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COAL AND COAL MINING

A RUDIMENTARY TREATISE

ON

COAL AND COAL MINING

By WARINGTON W. SMYTH, M.A., F.R.S.

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PREFACE.

THE following pages have been written as an elementary account of Coal, and the modes of working and raising it from the pits. Those who are familiar with the details of this great branch of British industry may probably object to the brevity with which portions of the subject have been treated; but I must plead in reply the narrow limits allotted me. I have endeavoured as far as possible to supply a general view of the methods and appliances employed in various districts, giving the fuller prominence to a description of the principal coal-producing regions at home and abroad, and of the various precautions needed for the preservation of human life.

Public attention has been forcibly called, whilst this work was in the printer's hands, to the question of the duration of the coalfields; and the Royal Commission, appointed during the last session of Parliament, testifies to the importance of providing our political economists with more accurate *data* than it has hitherto been possible to obtain. In my closing chapter the same topic has been somewhat briefly handled; and as I have dwelt, not on speculations, but on statistical facts and personal observation, I have seen no grounds, in the numerous speeches and writings produced within the last six months, for wishing to modify my statements.

Finally, whilst I would refer the student for ampler details to the treatises of M. Combes, M. Ponson, and M. Burat, Mr. Dunn, Mr. Greenwell, Mr. Hedley, and to other works mentioned in my text, I trust that this little introduction to Coal-mining bears internal evidence of not being mere extract of books, and that—whilst intended mainly to convey sound information to the unpractised—it may, nevertheless, contain matter of interest for viewers and overmen, to a long list of whom I have to express my thanks for many an instructive and agreeable day underground.

W. W. S.

LONDON, *September*, 1866.

PREFACE TO THE SECOND EDITION.

As the present publishers of this work intend to issue a new edition of it as one of the "Rudimentary Treatises," for which series it was originally written, the author has gladly availed himself of the opportunity to correct some errors which had escaped notice in the former edition.

He has also brought the statistics up to a recent date, and inserted notes bearing upon several important topics.

In the interval which has elapsed since the first publication of these pages, the most notable phase in coal-mining has been the attention bestowed by coal-viewers and engineers on the farther application of machinery to three departments of their art; viz., the getting of the coal, the underground haulage, and the ventilation of the works. Many coal-cutters and several ingenious contrivances for wedging down the seam by hydraulic power have been patented, but neither of them has been as yet so commonly applied as to need full description in a work professing only an elementary and general character. The latter two subjects have been admirably treated in the "Transactions of the Northern Institute of Mining Engineers," to which the author would refer his reader for details.

During the same interval the Royal Commission on Coal has, in completing its laborious task, allayed in great measure the public apprehension as to the early exhaustion of our fossil fuel, by making up a grand sum-total of coal in store—far beyond what moderate men had before estimated. Chapter XIX. should therefore be read with the understanding that its subject-matter has been most fully handled in the Report of the Commission. But, besides the copious harvest of facts, there is necessarily introduced a region of induction with more or less uncertainty attached to it, on which varying conclusions may be based. The duration of the coal-fields is a more intricate problem than might at first appear, and whilst nothing has been recently discovered seriously affecting the *data*, some of the opinions broached in his concluding chapter will, the author thinks, be found to be strongly supported by the movements and position of the coal trade and the colliers in the past year.

W. W. S.

LONDON, *July*, 1872.

PREFACE TO THE FIFTH EDITION.

At the time when the author penned the preface to the edition which appeared in 1872, the coal trade had been swollen into an exuberant prosperity, highly exhilarating for a time, but wholesome neither to men nor masters; and it appeared to the statistician a knotty problem how much higher the price of coal would rise, and to what gigantic figure our annual production would attain. But a period, first of check, and then of sad depression, has since taught us severe lessons.

The startling observation made about 1860—that the British output of coal is doubled in twenty years—held good till over the year 1877.

Thus, the total production was in	1858 . . .	65,008,649 tons.
„ „ „ „	1877 . . .	134,610,763 „

But at length, instead of the yearly increment of some 3,000,000 tons, a diminution has appeared which must tell upon the arguments of some of those who discussed the duration of the coal-fields.

The author has to thank Mr. Carruthers, F.R.S., the eminent botanist of the British Museum, for revising the chapter on the Plants of the Coal Measures, and bringing it abreast of the most recent views.

In the actual getting of coal, much attention has in the past few years been devoted to coal-cutting and wedging machinery, without as yet adequately satisfactory results.

In the same period a revolution has taken place throughout the country in the substitution, to a great extent, of mechanical agents for the furnaces employed in ventilation. In a less degree the pattern of engines is changing, and particularly in pumping, where the "special" and Davey's compound differential engine are gaining favour.

The Mines Regulation Act of 1872 is accused of having introduced sundry difficulties, and a palpable increase of cost in the raising of coal. It has the merit of drawing attention to many points which were apt to be neglected, but it has sometimes peremptorily decided on matters of detail which might perhaps better have been left open.

A change, which the author has for years watched in its advance, and to which he can refer as soundly and widely beneficial, is the general improvement brought about by the action of Institutes of mining Engineers. In these societies, now founded in most of our coal districts, the old local jealousies are swamped, and questions of practical work and scientific research investigated and described.

In so many instances has the author to recognise the value of the labours of these independent associations, that he must regard them as a most important factor in producing constant improvement by means of a higher cultivation.

W. W. S.

LONDON, *May*, 1880.

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COAL AND COAL-MINING.

CHAPTER I.

THE USE OF COAL: ITS COMMENCEMENT AND EXTENSION.

In these our modern days, surrounded as we are by coal fires, steam, and coal products, it is somewhat difficult to imagine ourselves in the position of the early writers on natural history, who touched with uncertain pen on what they thought to be the leading characters of a rare and ambiguous mineral. Many of the passages which have been quoted from ancient authors as indicating a knowledge of the use of coal have no reference whatever to the substance to which we now give the name, but indicate simply charcoal, or even wood-fuel. The translators of the Scriptures have thus employed the word *coal* in the same sense as the Greek *anthrax*, the Latin *carbo*, and the German *kohle;* the same, in fact, as was usual in our own language, until wood and charcoal came to be supplanted as fuel by their stony relative.

Certain varieties of this mineral were noticed by the ancients, although with little idea of the probability of their receiving any extensive application. Thus Theophrastus, the pupil of Aristotle, in an oft-quoted passage, described, nearly 300 years B.C., a fossil or

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stone coal of an earthy character, found in Liguria (now the province of Genoa), and in Elis, on the way to Olympias, capable of kindling and burning like charcoal, and employed by smiths. *Ampelitis*, a black stone "like bitumen," and *Gagates*, or jet, are mentioned by Pliny and others as available for medicinal or ornamental purposes; but neither the naturalists who endeavoured to describe the various products of creation, nor the historians who enumerated the sources of wealth of particular countries, leave us the impression of their having seen or heard of a generally useful fossil fuel. It has been attempted to show that the early Britons worked coal; and a stone axe, stated by Pennant to have been found in the out-crop of a coal seam in Wales, has been well-nigh worn out in the service; but we have no satisfactory evidence on the subject prior to the later days of the Roman occupation, when roads had been carried through many of the coal-producing districts. Coal cinders have been found amid the ruins of several of the Roman stations in Durham, Northumberland, and Lancashire, and more recently at Wroxeter, the ancient Uriconium, the destruction of which place dates, according to Mr. Thomas Wright, F.S.A., from the 6th century.*

It is not until the thirteenth century that we obtain clear proof that coals were systematically raised for fuel. In 1239 King Henry III. is stated to have granted a charter for this purpose to the townsmen of Newcastle-on-Tyne; and so early was the produce of their pits attracted to the devouring focus of London, that by the beginning of the next century great complaint arose on the injury done by the coal smoke to the health of the citizens. In 1306, on petition by Parliament, King Edward I., says Stowe, "by proclamation, prohibyted the burneing of sea-coale in London and the suburbs, to avoid the sulferous smoke and savour of the firing; and in the same proclamation commanded all persons to make their fires of wood." Not twenty years, however, passed away before the inevitable consequence of a gradually pressing scarcity of wood followed; the banished "sea-coale" again sailed up the Thames, landed in the capital, and actually effected a lodgment in the royal palace.* From that time forth, with a temporary check during the civil wars, the coal trade grew with the growth of the population, especially of London and the east coast, and *pari passu* with the rapid destruction of the forests.

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* The cinders were still on the ground adjoining the baths when the British Association excursion visited tne spot in September, 1865.

On the Continent the coal basin of Zwickau, in Saxony, appears to have been the earliest known in Germany, and it is said that its working can be carried back to the time of the Sorbenwends, about the tenth century. In 1348 the metal-workers of that town were forbidden to pollute the air with the smoke of coal. In Westphalia coals seem to have been dug near Dortmund as early as 1302.

The first mention of coal-mining in Scotland occurs in a grant executed in 1291 in favour of the abbot and convent of Dunfermline. Coal was probably worked on a small scale in several of the English and Welsh districts about this time; and we have the evidence of the quaint old traveller, Marco Polo, to show that the Chinese were at the same epoch well acquainted with its use.

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* "The History of Fossil Fuel." London, 1841.

One of the earliest manufactures which depended on the use of coal was glass-making, commenced about 1619 on the banks of the Tyne. In the year 1635 a proclamation of King Charles, prohibiting the importation of foreign glass, set forth that "Sir Robert Mansell had by his industry and great expense perfected that manufacture with sea-coal, or pit-coal, whereby not only the woods and timber of this kingdom are greatly preserved, but the making of all kinds of glass is established here, to the saving of much treasure at home, and the employment of great numbers of our people."

Up to the end of the seventeenth century pit-coal was employed for little else than household purposes; but it is not possible to obtain statistics of the quantities raised, excepting the amounts which were shipped. London and the east and south-east coast, as well as some continental ports, were supplied by Newcastle and Sunderland, which, about 1704, shipped off in a year respectively—

178,143 chaldrons, or 473,080 tons,
and
65,760 chaldrons, or 174,264 tons.

In 1750 the *vend* from both ports together amounted to 1,193,457 tons.

Dublin and the east coast of Ireland were supplied from Flintshire and Whitehaven; whilst the requirements of the rest of the country were variously contributed to by small workings in the Lancashire, Staffordshire, Warwickshire, and other coalfields. Many experiments had in the meanwhile been tried in Staffordshire and the Forest of Dean to substitute pit-coal for wood-coal in the smelting of iron; but before this great revolution in commerce could be accomplished, about one hundred and twenty years were to be occupied in trials, disappointments, losses, and delays.

Meanwhile the beginning of the eighteenth century was marked by the first wavering steps of the infant, Steam, so soon to develop into the mighty giant, depending for his strength on coal, himself making possible the extraction of the fuel from amid difficulties till then insurmountable, and opening out a thousand new methods for its consumption and application. Thus far coal had been valued for the production of HEAT only: it was now to enter upon a second phase of usefulness—that of the generation of FORCE. Already ingenious minds had pondered on the possibility of raising water from the mines by aid of the power of steam. Solomon de Caus, a French engineer, in his work, published in 1615, entitled "Les Raisons des Forces Mouvantes," proposed the experiment in scientific terms; and the Marquis of Worcester, in his "Century of Inventions," in 1655, rather dimly foreshadowed what might be done. But it was reserved for our countryman, Captain Thomas Savery, to apply the steam practically by the introduction of the principle of a vacuum, and to erect engines for the actual unwatering of mines at Great Work, in the parish of Breage, Cornwall, and in several other localities. In his paper, read to the Royal Society in 1699, and in his treatise, "The Miner's Friend," 1702, Savery describes the construction of his fire-engine, and renders it very clear that although the coals to be used were to be "of as little value as the coals commonly burned in the mouths of the coal-pits are," this ingenious invention, in which the water was first "sucked up" into a receiver by condensing the steam within it, and then forced up a stand-pipe by the direct impulse of the steam, required at least another step to fit it for general application. This step was the interposition of a piston, on the surface of which the steam should exert its power; and the application was ere long made by Newcomen. Some years, however, before this, Dr. Papin, a French refugee, had proposed an engine, in which a piston working in a cylinder should be raised by the explosive force of gunpowder, and then depressed, on the condensation of the gases, by atmospheric pressure. Soon afterwards he endeavoured to obtain the same result, so difficult of regulation with gunpowder, by introducing the elastic power of steam.* But although experiments were made at certain mines in the Auvergne and in Westphalia, Papin's contrivance was so far unsuccessful.

Newcomen appears to have been assisted by the suggestions of Dr. Hooke, the secretary of the Royal Society, and to have first tried his "fire-engine" on the large scale at a colliery near Wolverhampton. His mode of condensation by cooling the outside of the cylinder at every stroke proved to be inefficient, and it was only when he introduced an internal jet of cold water that success became decided. In concert with his assistant, Calley of Dartmouth, he erected near Newcastle and in Yorkshire several engines of 23 inches cylinder, and in 1720 constructed at Wheal Fortune, in Ludgvan, an engine with cylinder of 47 inches diameter, working 15-inch pumps, to be soon followed by others at Wheal Rose, near Redruth,

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* The engine with its piston (*pistillum*) is described and figured in the "Acta Eruditorum," Lipsiæ, 1707.

Wheal Busy, and Polgooth mines. Coal was burnt under their clumsy dome-shaped boilers at a fearful rate; but what matter? It must be done, if the hidden treasures of tin in the west, and coal in the north were to be followed up to depths that had been proved unattainable by aid of the water-power at the command of the mines. The convenience with which the new invention could be applied caused it again often to be used as a lifter of water to the top of water-wheels; and thus whether applying its force directly or indirectly, it prospered, and spread through the length and breadth of the land. A few of these old Newcomens, or atmospheric engines, working the pump-rods with the intervention of a horizontal "beam," or "bob," and more or less patched and modified, have survived even to our own times.

About the time that the miners began to employ on a large scale the facilities afforded them by the new fire-engine, there arose from another side an application of coal, founded upon its calorific power and on the action of the gaseous products of its combustion. Between 1730 and 1735, Mr. Abraham Darby, of Coalbrook Dale, in Shropshire, succeeded at length, through the introduction of the process of coking, in smelting iron with pit-coal. The iron trade of Great Britain had at that period sunk to a very low ebb, but was now destined to rise to a height which is one of the great marvels of all the world, and that in a chief measure by the employment of the beds of mineral fuel so wondrously stored up in close proximity to the iron ores which have formed the great staple of our manufacture.

Still, during all this period we have no general statistics of coal. More and more of it came to be works, saved so large a proportion of the coal needed for the smelting of each ton of pig-iron, that the great majority of the iron works were forced by competition to adopt the same method; and in spite of a very common belief that the quality of the produce was thereby injured, the result has been an enormous increase of the total quantity of coal used for this purpose, with a much greater increase to the iron trade. If we take, as an example, the results in Scotland, we find that the ton of pig-iron, as made in 1829 at the Clyde Iron Works, required the coke of 8 tons 1¼ cwt. of coal, whilst in the following year the introduction of air heated to 300° Fahr. brought down the consumption per ton of pig to 5 tons 3¼ cwts. Eight cwts. of coal were consumed in heating the blast, so that the actual saving per ton of pig-iron was 2½ tons. In 1833, when raw coal had come to be used instead of coke, 1 ton of pig-iron was made with 2 tons 5¼ cwts. of coal, which, with 8 cwts. for heating the blast, made a total of 2 tons 13 cwts. Hence by the application of the hot blast, the same amount of fuel reduced three times as much iron, and the same amount of blast did twice as much work as previously.*

Now the production of pig-iron in Scotland has risen as follows:—

	Tons.
1820	20,000.
1830	37,500.
1839	200,000.
1851	775,000.
1861	950,000.
1864	1,158,750.

Whence, at the rates above quoted, the total consumption of coal in iron smelting would have been, in

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* Percy's "Metallurgy of Iron," p. 398.

	Tons.
1820	161,250.
1864	2,621,671.

It must not however be concluded that this enormous development in the Scotch trade was due to the hot blast alone. Concurrent with that great improvement was the employment of the abundant and economical mixture, the "blackband," for the discovery of which Britain is indebted to Mr. Mushet. But the main fact remains—that every advance which tends to cheapen the productions of manufacture enlarges so widely the field of operations, that coal, the basis of the whole of them, is always demanded in ever-increasing quantity.

In the absence of accurate *data* it is estimated that in Great Britain about ten millions of tons of coal were raised in a year at the beginning of this century. The continental production at the time was exceedingly small, the backwardness of many manufactures and the large expanses of forest land having delayed the necessity for turning to subterranean fuel. Within a short time after the conclusion of the great war, steam-engines were rapidly supplanting or acting as auxiliaries to water power, and the coalfields of our own and foreign districts became the scene of more active researches. But it was not until the facilitation of traffic by means of steamboats and railroads, that the steady, absorbing march of the present epoch commenced. When between 1829 and 1835, the locomotive engines running on wrought-iron lines, and the coasting and sea-going steamers, were proved to be a triumphant success, leading to imitation in foreign countries, and to enormous multiplication in our own, a new system of the distribution of raw material may almost be said to have been started. Nowhere is the result more striking than in the London district, which now receives by sea, railway, and canal, upwards of *five millions of tons* per annum, or doubtless more than the production of the entire kingdom in the earlier years of George III.

Many new and striking applications of coal have within the last few years rewarded the exertions of chemists. The once useless and fetid products of its distillation have been made to yield sweet scents and savours. From its *naphtha* are obtained the paraffine oil and the beautiful translucent solid paraffine, which in brilliancy and purity excels wax itself; and from its *aniline* are obtained a galaxy of brilliant colours, among which need only be mentioned the popular *mauve* and *magenta* to prove the varied forms under which the products of coal have found their way into the useful arts.

The International Exhibition of 1851, possible only under these conditions of mechanical advancement to which we have referred, naturally directed the attention of inquirers more forcibly to the statistics of mineral produce. It was roughly estimated that for 1850 the production of all the British coal-mines was 42,000,000 tons; France was raising 4,433,000 tons; Prussia and Belgium followed, with smaller quantities; and then Austria, with a little above 1,000,000 tons.

In 1853, Mr. T. Y. Hall, of Newcastle, after much investigation, stated the British production to be 56,550,000 tons.

At length, in 1854, through the instrumentality of Mr. Robert Hunt, of the Government Mining Record Office, aided by the recently appointed inspectors of coal-mines, we obtain reliable statistics; and the following table will command the attention, if it does not excite the astonishment, of every reader.

Coal Production of Great Britain.

	Tons.			Tons.
1854.	64,661,401,	of which	were exported	4,309,255*
1864.	92,787,873	„	„	8,063,846
1874.	125,043,257	„	„	13,927,205
1875.	131,867,105	„	„	14,544,916
1876.	133,344,766	„	„	16,299,077
1877.	134,610,763	„	„	15,420,050
1878.	132,607,866	„	„	15,494,633

The vast quantity represented by these figures may be brought before the eye by the following comparisons, supposing that we take the approximation of one ton being, as it lies densely packed in the earth, one cubic yard. If we take the area of Lincoln's Inn Fields, measured up close to the houses, at eleven acres, about the dimensions of the base of the Great Pyramid, and could stack the coal as nature has done in the seams, the British coal raised in 1865 would form, on that base, a solid block, of the height of 5,229 feet, or as high as Snowdon surmounted by another mountain of half its height.

Again, taking the distance from London to Edinburgh, four hundred miles, the same quantity, similarly packed, would build a wall the whole way, of twelve feet thick and ninety-nine feet high; whilst if put together in the broken state in which coal is commonly used, it would give a wall of more than double that thickness.

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* The exports of 1854 alone are from the returns to the House of Commons, the remaining numbers are taken from the statistics compiled by Mr. Robert Hunt, F.R.S., Mining Record Office, Museum of Practical Geology.

This yearly production, obtained by the labour of about 240,000 men,* is palpably a gigantic effort for so small an area as that of our united coalfields, and naturally excites apprehension for the future.

The statistics of the produce of the mines of most of the European nations are well kept up, although a few of them can only be roughly estimated, and it is interesting to compare the

ANNUAL AMOUNT PRODUCED BY THE CHIEF COAL-BEARING COUNTRIES.

	Tons.	Tons (1877).
Great Britain and Ireland (1870) . . .	110,431,192	134,610,763
United States of America (1871), *estimate* .	33,637,486	49,130,584
†Prussia, including Silesia, &c. (1870) . .	29,432,756	42,308,622
Saxony (1869)	3,096,231	3,477,511
German States, beside the two last (1869) .	1,471,899	2,443,749
Austrian States (1870)	7,084,391	14,252,038
Belgium (1870)	13,697,110	13,938,523
France (1869)	13,100,000	16,889,201
Russia (1870)	800,000	1,900,000
Province of Nova Scotia (1871)	597,418	757,496
New South Wales (1869)	919,522	1,444,171

It is hence evident that although our favoured country has so long taken the lead, all civilised countries have entered into the race of competition; and it becomes a matter of anxious inquiry to learn under what circumstances the treasure is in each country developed, and where it is likely to be best expended or longest economised.

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* Now increased, in 1878, to 475,329 persons.

† Given in the official statistics in *zollcentner*, of which 20 = 1 ton English, nearly. The German *tonne* is 1,000 kilograms, or 2,000 pounds, the pound being 0·5 kilogram.

CHAPTER II.

MODE OF OCCURRENCE OF COAL.

The substance receiving the name of true coal (in contradistinction to lignite and brown coal) is, in almost all the coal-producing countries, found in beds or seams divided from one another by more or less thick *strata* or beds of shale, sandstone or grit, and indurated clay, the whole being termed collectively the Coal Measures, and belonging to a still larger group of stratified rocks called the Carboniferous Formation or System (*Systême houillière*, or *anthraxifère*, Fr.—*Steinkohlen-gebirge*, Ger.).

It is difficult to define exactly what constitutes a Coal. Several legal trials on a grand scale, in Edinburgh, London, and in Prussia, have only succeeded in making it more clear than ever that no suitable definition exists, and that whilst all parties may agree in recognising the characters of a typical coal, differences of opinion will soon arise when the substance to be determined approaches the boundary of the shales and of the bitumens.

It is obviously loose to assert that "anything is a coal which is dug out of the earth and will burn;" whilst on the other hand it is inconveniently strict to demand any approach to a definite composition as indispensable to coal. We may fairly require of it that it be black or dark brown, capable of direct employment in furnaces and fire-places for the production of heat, brittle, and not soluble—like the bitumens—in ether, oil of turpentine, or benzole. The following are the chief characters of the various substances regarded as coals.

ANTHRACITE (Stone, Kilkenny, or Crow-coal). Black, with black streak; fracture, conchoidal; does not soil the fingers; specific gravity, 1·3 to 1·75; less easily kindled than other kinds of coal; often decrepitates much in burning; composition, carbon in great proportion, generally 90 to 95 per cent., hydrogen, oxygen, and nitrogen in minute quantities.

BITUMINOUS COAL. Black, of various shades, streak sometimes greyish black; lustre, more waxy than that of anthracite, in some varieties dull; fracture, subconchoidal to uneven, the substance often divided by cleats or joints into parallel-faced figures (*cubical coal, dicey, &c.*); specific gravity, 1·25 to 1·4; composition, generally from 73 to 90 per cent. of carbon, 8 to 22 per cent. of oxygen, hydrogen, and nitrogen, with (as in anthracite) a variable amount (3 to 30 per cent.) of earthy matter constituting the "ash."

The term *bituminous coal* is somewhat deceptive, and it must be remembered that it does not mean that any bitumen (or mineral pitch, soluble in ether, &c.) is contained in it, but that the gases, oxygen, hydrogen, and nitrogen, enter more largely into its composition than in anthracite, and give it a more flaming character in burning. The varieties generally recognised are mostly named after their application or chief properties: *Free-burning, steam* or *smokeless coal, non-caking coal.* These, in different grades, approach towards the anthracites, and are chiefly valued for engine and smelting purposes. They often exhibit, in parts of the seams at least, a peculiar fibrous structure, passing into a singular toothed arrangement of the particles, called *cone-in-cone*, or "crytallised coal." Some of these "dry" coals will coke, but the smalls, from their not agglutinating, cannot be used for that purpose. With the addition, however, of pitch or tar to the amount of 8 or 10 per cent., the small may be made into "patent fuel," or "agglomerated coal."

Caking-coals are those which tend to partially fuse when burning; emitting jets of gas, and, as a rule, giving off abundant flame and smoke. The "household coals" are generally of this variety, and are valued in great measure according to their freedom from ash. The "smalls" have the valuable property of fusing together into large masses when duly heated; whence they are abundantly turned into coke for iron-smelting and for burning in locomotives.

A single seam or bed often contains layers of different descriptions of coal, which may in some cases advantageously be divided from one another and separately sold for divers commercial purposes.

A remarkable instance of this was noticed by me in the "Top-hard," a famous Derbyshire and Yorkshire seam, at Handsworth, where its aggregate thickness was 55 inches. The divisions were as follows :—

	Inches.	
Roof coal	2	useless, thrown away.
Batt (black shale)	2	
Brassy piece (pyritous)	5	
Rough bright	4	for house fires.
Best bright	4	good for making soft coke.
Top hard	4	"converting" coal, for steel making.
Dead bed	8	
Bottom hard	1	
Rough bright	6	for house fires.
Soft bright	3	for soft coke.
Dirt, parting,	9 to 12	
Holing coal	4	very dusty soft coal
	55	

Cannel is commonly considered a variety of bituminous coal, with the beds of which it is not unfrequently associated in parallel layers; but it is a fair question whether it should not, in scientific nomenclature, be separated from the coals proper. It is black or brownish, dull in lustre, breaks with a flat conchoidal fracture, is not made up like ordinary coal of thin laminæ, does not soil the fingers, often contains teeth and scales of fishes, and, according to some of our best microscopists, is readily distinguishable from coal by the general absence of vegetable structure. Its name, from *cannyl*, a "candle," is derived from the readiness with which it lights and gives off a steady flame. Some varieties, however—*parrot* coal (Scotland) and *rattlers* (Yorkshire)—decrepitate and crack loudly on the fire. Cannel is largely employed for gas-making.

It is by no means easy, if at all feasible, to draw a distinct line of demarcation between cannel and the black *basses*, *bats*, or crisp shales, which occur in the coal measures, but contain too much earthy matter to allow them to be of present value. And between all these and the *torbanite*, or "Boghead mineral," there exists a relationship which makes the difference only one of degree. This last is a brown, tough substance, containing little more than 9 per cent. of carbon, 60 to 69 per cent. of volatile matter, and the "ash" so abundant and so equably diffused through the mass, that when the mineral has been "burnt," or had the volatile parts extracted by distillation, it is taken out of the retort blanched in colour, but in volume looking just as when it was put in. Its great value consists in its oil and gas-yielding properties—a ton of this mineral giving as much as 15,400 cubic feet of gas, whilst good cannels give but 8,000 to 10,000 feet. *Torbanite* is classed by some authors as a distinct mineral species, and by others as a bituminous shale.

Lastly, we have BROWN COAL, or LIGNITE, a mineral —more distinctly than any of the foregoing—formed of a mass of vegetable matter; some stems, in fact (lignite proper), presenting the appearance of undecomposed wood. Colour, brown to pitch-black; lustre sometimes resinous, sometimes dull; specific gravity 0·5 to 1·5.; fracture various; burns easily, with a smoky flame and unpleasant odour. Composition, 50 to 70 per cent. of carbon, a much larger proportion of oxygen than in the bituminous coals, hydrogen and nitrogen about the same. A large amount of water generally present. Varieties of it are termed—according to their aggregation—*pitchy*-coal (*pech kohle*), *slaty*-coal (*schiefer kohle*), *paper*-coal or *dysodil*, *bast*-coal, *needle*-coal, and *earthy*-coal.

Certain examples of the brown coal of the better sort so closely resemble the good bituminous coals as to be indistinguishable by any trenchant difference of composition in appearance. It has, however, been usual to apply this name to all the coals which occur in formations more recent than the true carboniferous period. Thus the name brown coal—not a very happy one—embraces as many qualities and varieties as does the old family name COAL, from which it is now held to be a distinct off-shoot.

For a general account of the geological phenomena which have to do with the occurrence of the coal-measures, we must refer the reader to the "Treatise on Geology," by the late General Portlock,* or to some of the various "handbooks" and "manuals" already before the public. We have only space in the present little volume to deal with those parts of the subject which are more specially related to the finding and working of coal.

Our descriptions will almost entirely have reference to the strata of the true carboniferous system, as being without comparison the most important. It is there, in the upper part of the *Palæozoic* or "ancient life" division of the earth's crust, that the great coalfields of the world are sought out and worked. But some countries, as Italy, for example, are not fortunate enough to possess any of these within the ken of man, and must content themselves with brown coal alone; others, like Hungary, have brown coal of several successive periods and of very different qualities. Much value will then attach, locally, to this minority among the coals, and the following table will show with clearness the succession of the entire series of strata in their true geological sequence, along with the different classes of coal which they have been proved to contain.

It is to be remembered that whilst the annexed table exhibits the natural sequence where all the strata are developed, it frequently happens that some of them are missing from their places. Thus, in Belgium and North France the coal-measures lie immediately beneath the chalk or cretaceous beds. In South Staffordshire the carboniferous limestone and other strata under the coal, down to the Silurian rocks, are wanting. In South France (St. Etienne) all stratified rocks are absent, and the coal-measures rest directly

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* Weale's Rudimentary Series.

TABLE OF THE STRATIFIED ROCKS.

Showing the position of Beds of Fossil Fuel.

	Group.	Chief Divisions.	Locality of Coal or Brown Coal.
TERTIARY, OR CAINOZOIC.	Pleiocene.	Norwich Crag. Red and Coralline Crag.	Surturbrand lignite, Iceland.
	Miocene.	Faluns of Touraine, Molasse Sandstones, &c.	Austrian Alps. Germany. Leafbeds in Mull. Lignite in Antrim? Vancouver Island. Bovey, Devon (Heer).
	Eocene.	Bagshot Sands. London Clay. Woolwich Beds, &c.	Tyrol, and the Venetian Alps. South Styria, some beds of fathoms in thickness.
SECONDARY, OR MESOZOIC.	Cretaceous.	Upper Chalk. Lower Chalk. Chalk Marl. Upper Greensand. Gault. Lower Greensand.	Austrian Alps, in the Gosau beds. Coal, up to 4 ft. thick, Lettowitz, &c., in Moravia. Santa Fé de Bogota, South America.
	Wealden.	Weald Clay. Hastings Sand.	Good brown Coal beds in North Germany, Utrillas, &c. N.E. Spain?
	Oolitic or Jurassic.	Portland Oolites. Oxford do. Bath do. The Lias.	Purbeck *dirt-bed*, with Lignite. Mori, Tyrol. Kimmeridge "coal." Productive coal in Lower Oolite, Brora; Yorkshire; Pennsylvania. Excellent coal at Fünfkirchen, and Steierdorf in South Hungary.
	Trias.	Rhœtic beds. Keuper. Muschelkalk. New red Sandstone.	Keupercoal, *Lettenkohle*, S. Germany. Virginia, U.S.
PRIMARY, OR PALÆOZOIC.	Permian.	New red, in part. Magnesian Limestone. Lower red Sand.	Coalfields of India not older than this? and *Brandschiefer* Germany and Bohemia.
	Carboniferous.	Coal-measures, often divisible into 3 groups. Millstone grit. Carboniferous Limestone.	True Coal in England, Scotland, Wales, France, Belgium, Prussia, Bohemia, Moravia, Spain, the United States, Nova Scotia. Anthracite in South Wales, Ireland, Pennsylvania. Coals in North England. Coal in Northumberland, Scotland, Russia.
	Devonian.	Old red Sandstone. Slaty rocks, *Killas*, &c.	New South Wales Coals appear to belong to period from hence up to the Trias.
	Silurian.	Ludlow rocks, &c. Bala beds. Llandeilo Flags. Cambro-Silurian Slates.	Petroleum, in these three lower groups. Anthracite in Co. Cavan, and Isle of Man (Laxey mine); Norway.

upon granite. Similarly, it has to be borne in mind that the coal itself may possibly not be present, although the group above it and the group below it may be in their places; but the *order of the superposition* is never changed.

Those who learn their practical lesson in one single coalfield are apt to acquire notions about the physical conditions which require to be corrected by visits to other districts, to make them capable of general application. Thus, whilst the total thickness of the coal-measures in Shropshire and South Staffordshire is only from 1,000 to 1,600 feet in thickness, in North Staffordshire it reaches 5,000 feet, in South Wales 14,000 or 15,000 feet, and in Saarbrücken, in Prussia, no less than 20,000 feet.

The great bulk of the series of rocks, termed *coal-measures*, consists of shales or indurated slaty clay, variously coloured grey, bluish, or black (*clod*, *bind*, *batt*, *metal*, &c., of the colliers); of dense clays, a bed of which almost invariably underlies every seam of coal (*warrant*, *pounson*, *clunch*, &c.); and of sandstone (*post*, *rock*, or *stone*) of various degrees of hardness and roughness of grain, though seldom containing pebbles, except in the strata which occupy quite the lower part of the series. The actual beds of coal, then, from an inch or two thick, up to 8 or 10 feet (generally considered "workable" when above 18 inches or 2 feet in thickness), and making up in the aggregate perhaps 100 feet of coal, form but an inconsiderable part, in dimensions, of the great mass of rocks with which they are interstratified.

Whatever may be the form of the surface of the ground, it rarely happens that the coal-measures under it, whether deep or shallow, lie in a flat position for more than a small distance. They are found to incline (*dip* or *pitch*) more or less regularly from the moderate angles of 6 or 8° to as much as 25 or 30°, a "sharp pitching," or even in exceptional cases to 70 or 80° (*rearing* or *edge* seams). Whatever happens in this way to one of the beds, the others are similarly affected, because the strata throughout this system or group are all *conformable* or parallel.*

The inclined position of the beds will necessarily bring them at some point or other to the surface, unless they are overlaid by some newer formation deposited *unconformably* upon the ends of the upturned strata. Hence it is that a great insight into the character of a coal district may be obtained by a careful study of the surface, especially in brook-courses, which run more or less in the direction of the dip and rise of the seams. If we follow out the subject over a larger area, we shall find many variations to take place, and the coalfield assuming a form which may be traced as on a map if the tract be surrounded by older formations, but about which there will be uncertainty if the measures are observed to dip beneath other and newer groups of rock. When the beds dip for a while and then ascend or rise, they form a *trough* or saddle, and when they rise on all sides towards the surface, as in the Forest of Dean, they constitute a *basin*. The outline of the shapes into which the coalfields have been brought by the forces of elevation and depression may be studied in the geological maps; but where these forces have exercised their powers on a grander scale, the measures are often folded back, corrugated, or contorted in such a manner as to present great complexity. Examples of this may be seen in Pembrokeshire, at Vobster, Somersetshire, and in the Belgian coalfield.

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* Certain cases have been observed in which one portion of the coal-measures is slightly unconformable to another; but this does not interfere with the doctrine of the general parallelism of the beds.

In addition to this general disturbance from the original—more or less horizontal—position in which the beds must have been deposited, they have been cut through by inclined planes of fissure, and so dislocated that they are now lower on the one side of the line of fault than on the other. The amount of *throw* or *leap* may be only a few inches or feet, in which case the workings are not much affected; but the movement may in many instances be shown to have arrived at hundreds, and more rarely, to thousands, of feet. A great number of these *troubles* within a small space may render a seam of coal so "faulty" as to be worthless; whilst, if they are filled with clay, and suitably distant from one another, they serve a useful purpose in dividing a coalfield into water-tight compartments, and a jealous eye is thence kept on their security.

If we now turn back from the larger view of the whole group of strata, and look at the seam itself, we shall note, first, its thickness,—an amount varying generally from 18 inches to 8 feet. In Somersetshire they contrive to work seams with only 11 inches of coal! At Whitehaven and in the upper measures in Fintshire, seams of 10 and 12 feet thick are worked. In South Staffordshire, 30 to 36 feet, at Pictou, Nova Scotia, 36 feet, and at Pottsville, U.S., 40 feet, are the thicknesses of exceptional seams, put together by the superposition of several of ordinary dimensions. A very thick one will rarely be of clean coal throughout;

partings will occur, of clod or various earthy material, which, if of a few inches, may not occasion much inconvenience, but if they get to be more than 18 inches or 2 feet, may practically interfere with the possibility of working advantageously. Iron pyrites or *brasses* will sometimes run with a line of parting, and needs to be carefully picked out. The partings are often mere planes of division, and are then sometimes smooth surfaces, *slicks*, requiring caution in undercutting; but are more generally films of black, soft, and fibrous coaly matter, apparently made up of small fragments of carbonised wood. Then comes the physical condition of the coal, to whichever of the kinds above enumerated it may belong. Is it dense, hard and unjointed, it will be expensive to cut, but more valuable from giving a large proportion of "round" or massive coal. Is it divided, like the Derbyshire, by one set of *backs* or *faces*, running most regularly parallel, it will need a special direction of the working faces. Is it, on the contrary, divided by two sets of divisional *cleat*, as in some of the Northern coal, the direction is not so important. These divisional planes are generally almost vertical, but in South Wales (Pontypool, Merthyr, &c.) they dip at a considerable angle; and when they here and there meet a "rider" inclined the other way, they form a loose mass of coal, very dangerous to unwary colliers.

The *floor*, *thill*, or *seat* (*pavement*, Scot.), of the coal is an underclay, generally good for fire-brick: if soft, it is apt to heave, under the pressure from above, into the opened roads, and greatly to multiply expenses. Here and there a quartzose silt forms the seat, especially in some of the lowest seams (Yorkshire, Lancashire, &c.)

It is so hard as to make a capital road stone, known as *ganister*, but bears the black rootlets thick in it, which we see in the ordinary bottom-clay, *spaven*, or *warrant*. The ganister is commonly a foot or 20 inches in thickness, and has clay again beneath it.

Lastly, the *roof* or *top* of the seam is one of the most important items in the economy of its working. A good tenacious shale or bind is the most favourable. But rock or sandstone roofs there are, which will hold up for a very great breadth of ground, and come down pretty manageably, whilst others can hardly be trusted. It is most fortunate that the frequent planes of division which almost invariably split up the coal, do not pass up into the roofs. If the immediate cover of the coal be too short or soft or cracky to stand well, it may be necessary to leave some inches of coal as a roof, or again (depending on the strata overhead), it may be better to rip down a foot or two (or even four or five feet sometimes) to afford security to the roads

It must not be forgotten that although the coal-seams are, as a rule, more persistent and regular than any of the beds of rock which accompany them, they are subject to variations which may influence their value, and often within a small area. The thinning by a gradual depression of the roof till sometimes the entire coal is gone, but for a certain width only, is a kind of fault (*nip* or *want*), that has often been noticed, and is confined to one seam, not affecting, or only slightly, those above it or below it. An interesting example of this kind occurs at Denby Colliery, Derbyshire, where a channel of 320 yards wide was found eroded in the "deep hard" coal for half a mile in length, whilst the next seam above it, the "upper soft coal," has proved continuous, and been worked over the entire area. Another sort of thinning is where the floor rises, if sharply, in a "hog-back" or saddle; if gently, like a swelling undulation, which subsides again in 10, 20, or 40 yards, and is succeeded sometimes not merely by the usual normal thickness of the coal, but by an exceptional amount, to make up as it were for the thinness to which it had before been reduced.

One of the most notable examples of this kind is in the fine colliery of Seaton Delaval, where throughout a depression of 1,000 yards in length between the old and the new or Forster pits, and for 120 yards wide, the seam is from six to seven feet thick, whilst on both sides it dwindles rapidly till much of it is but 2 feet 6 inches, and has been unworkable.

In the Forest of Dean the Coleford high Delf seam, averaging 4½ feet thick, is here and there reduced to much less, and then rapidly expands till (Miles' Level colliery) it attains 9 and even 11 feet thickness. Variations so considerable are more frequent in the lower than the upper coals, and coupled with the smoothly polished under surface which may occasionally be noticed, lead me to think that the coal must have remained in a plastic condition long after it was covered up with sediment, and that it has been much squeezed and moulded by the various movements to which the strata have been subjected.

The introduction of bands of foreign matter, as partings, between the laminæ of the coal, has already been described; and these, so apt in particular districts to multiply as well as to increase in bulk, are frequently to be added to the other elements of uncertainty which, in some regions more than others, render coal-mining a more speculative undertaking than it at first sight would appear to be.

CHAPTER III.

ORGANIC REMAINS, AND ORIGIN OF COAL.

Not a doubt can exist in the minds of those who have either observed for themselves or fairly examined the description of others, that the coal has been produced from an accumulation of the remains of various kinds of plants. The bed of fire-clay or *clunch* which lies beneath each seam is full of roots and rootlets; the shale overhead is often so charged with the brightly preserved fronds of ferns, flattened trunks, and various strange forms of leaf, as to rival all that can be shown in a princely conservatory. The sandstones contain fragmentary trunks and branches, and the coal itself may often be seen, on carefully dividing its laminæ, to show the impressions of numerous vegetables, with at intervals a film of soft silky "mineral charcoal;" whilst occasionally the structure of the plants has been preserved by mineralisation, revealing in their slices under the microscope the Flora of the primeval world.

These appearances vary much in different coalfields, and in the different seams of a single field. Certain authors, especially Dr. Göppert, of Breslau, are of opinion that many seams can be safely distinguished by the difference of the plants associated with them. Mr. Salter, following Mr. Binney and Professor Phillips, has recently endeavoured to show, for certain seams of our own country, that there are useful distinguishing characters in the animal remains (mollusca, fish, &c.) which often occur in the roof shales. But the subject, noble and every way interesting, has strangely been left to the handling of occasional visitors of collieries, and needs much further inquiry.

We will endeavour to put together a brief synopsis of the principal forms of vegetation which are met with in the coal-measures, premising only that whilst some 500 different plants, derived from this source, have been described, a short sketch like the present will be mainly useful if it lead the inquirer to study the works of some of the authors who have contributed to this branch of knowledge—Witham, Lindley, and Hutton, Brongniart, Göppert, Binney, Sternberg, Corda, Dawson, Williamson, Hooker, and Schimper.

SIGILLARIA. A great proportion of the actual coal appears to have been formed of this plant, which is often represented in the shale by the bark alone. They are sometimes as much as 3 to 5 feet in diameter, and 30 to 60 feet in length. Their beautiful fluted and symmetrically scarred patterns may often be seen crossing one another in luxuriant confusion in the roof from under which the coal has been removed. I had an excellent opportunity some years ago, in conjunction with Mr. Beete Jukes, of observing the bared upper surfaces of successive steps of the Dudley thick coal when it was being worked open to the daylight, and when they all showed fine impressions of *Sigillaria.*

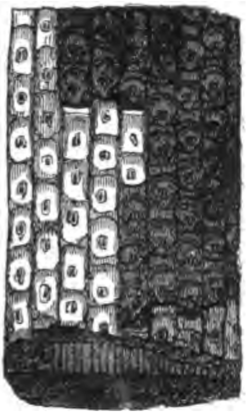

Fig. 1. Sigillaria elegans. Forest of Dean. (Half the natural size.)

Eighty-three species are described by Schimper in his great work. They are allied to the humble club mosses of the present world. *Sigillaria* stems of full thickness and a few feet in height are frequently found erect, sometimes hundreds together in a very small area. Often they stand based close upon the seam of coal, and most unfortunately for the safety of our colliers, since the film of coal representing the bark which surrounds them, separates them from the surrounding matrix, and they are apt to drop out without warning, in a mass weighing from a few cwts. to a ton. They are thus commonly known as bell-moulds, coal-pipes, or cauldron-bottoms, and may be traced by a slight circular outline, often formed of bright coal.

STIGMARIA. The curious fossil found so universally in the clays or indurated silts beneath the coal, was long supposed to belong to a distinct family, but the researches of Mr. Binney in Lancashire, and Mr. Richard Brown in Nova Scotia, have proved it to be the root of *Sigillaria*. From the central boss great

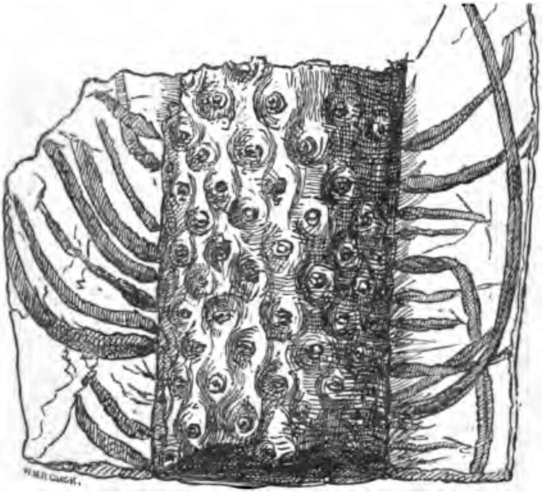

Fig. 2. Stigmaria ficoides. (Half natural size.)

cylindrical arms extended in every direction, branching oftentimes into two, and the smaller ones into two again, and thus occupying an area of many yards. From the little tubercles regularly arranged on the root were given off innumerable rootlets, which we now find squeezed into narrow carbonised ribands, confusedly interlaced with the clay, and stretching for many feet away. These are found retaining their original form when they have been preserved by being embedded in a quartzose silt, like the *ganister* bed of some of the lower coals, when it becomes evident that each was attached by a curious rounded base resembling a ball and socket joint.

Lepidodendron. The trees of this beautifully marked family also attained a length of upwards of forty feet, and are referred to some sixty species. The size is the more extraordinary when we realise that like the *Sigillaria* they belong to the *Lycopodiaceæ*

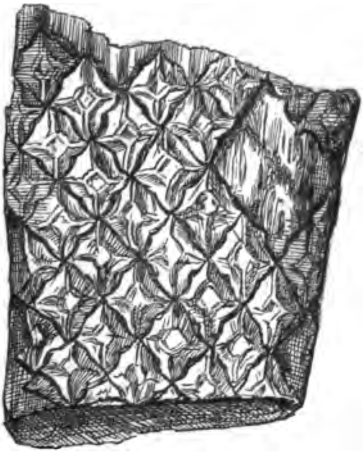

Fig. 3. Lepidodendron obovatum. (Half natural size. (Le Botwood Colliery, Shropshire.)

or club-mosses, the largest of which now living in tropical climates attains a height of only a few feet.

An elegant cone, often found well preserved in ironstone among the coal shales, and termed *Lepidostrobus*, is the fruit or catkin of the *Lepidodendron*.

Halonia, a stem from 2 to 4 inches thick, looking in outline like a knotty blackthorn, is a branch of a *Lepidodendron* on which were borne sessile cones.

CALAMITES. Jointed and striated stems occurring abundantly in some of the shales have been compared by the unlearned with bamboo, but belong to the *Equisetaceæ*. The fruits have been discovered beautifully preserved and have been described by Carruthers, Schimper, and Williamson, and their affinities with *Equisetium* established. The views of Brongniart that two groups of plants, one Cryptogamous and the other Phanerogamous, are included in the plants generally called Calamites, though still held by some French authors, cannot be maintained. These palæozoic *Equisetaceæ* do not differ more from their living allies than the *Sigillaria* and *Lepidodendra* from living *Lycopodiaceæ*.

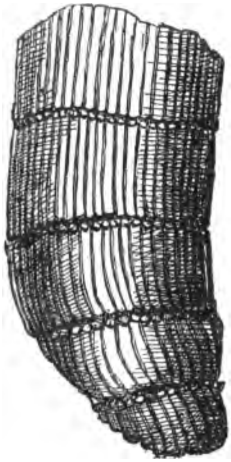

Fig. 4. Calamites decoratus.
Derbyshire.
(Half natural size.)

The Calamites have also been found in their original erect position, the root end tapering and curved towards the main axis.* They seem to have formed a dense brake of perhaps half the height of the *Sigillariæ.*

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* The conical end used to be taken for the top of the stem, and sometimes by collectors for a fish's snout.

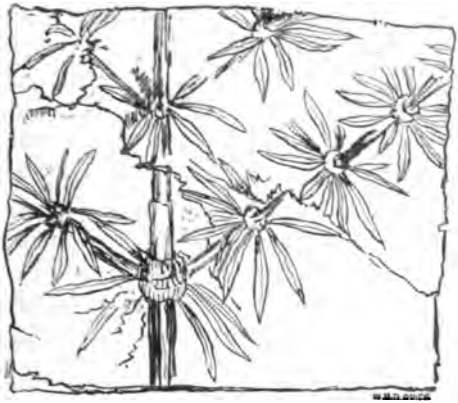

Fig. 5. Asterophyllites equesetiformis. Forest of Dean. (Natural size.)

ASTEROPHYLLITES, *Annularia* and *Sphenophyllum.* These consist of branches with leaves arranged in whorls or stars. They are the foliage of the Calamites, and perhaps represent as many distinct *genera.* Various fruits have been described which may be co-related with these leaves and thus supply good generic characters.

CONIFERÆ, or FIRS. Among the trunks found petrified in the sandstones, many exhibit under the microscope a structure which appears to indicate their relation to the Araucarias, of which the species brought from Norfolk Island is a well-known modern representative. The coal-pines were peculiar from containing a very large pith, which, found separately as a ringed cylinder, used to be described as an independent plant, under the name *Sternbergia.* Angular, nut-looking fruits, called *Trigonocarpum,* are referred to this class of trees; and these would imply an affinity rather with the Taxineous group of Conifers, but the have not yet been obtained specimens to show the relation of the fruits to the stems.

Again, in the films of soft mineral charcoal or "mother-of-coal," which, of the thickness of a knife-blade to a quarter of an inch (rarely), run evenly between the brighter laminæ of the coal, frequent in some, absent in other seams, the angular fragments of woody-looking substance, all mashed up together, present in many instances this araucarian structure. Other portions exhibit a *bast* tissue, or elongated cells, from the bark of *Sigillaria* and *Lepidodendron.*

Of this highly organised class of trees, the most abundant remains are referred to one genus called *Araucarioxylon.*

Ferns, or Filicites. These graceful relics of a former world of vegetation adorn the shaly roofs of many of the coal seams, sometimes clearly spread with their black tracery on a grey ground, a true specimen of nature-printing; at others tossed and tumbled in wild profusion throughout several feet in thickness of the roof-stone. A careful eye, and still better if aided by a microscope, may often see their traces in the coal itself, and in some of its dull unpromising parts may descry innumerable spiculæ or hair-like needles, which Dr. Dawson refers to the vascular bundles of decomposed plants of this tribe.

Certain botanists have named and described hundreds of species; others, more cautious, remind us that considerable difference of appearance may be seen on the several fronds of one plant, or even on the *pinnæ* of the same frond; and that the number of species may thence have to be reduced.

A general resemblance to ferns of the present day must not be confounded with identity of species or even genus. It is to be remembered that the whole of the coal-measure ferns are utterly extinct, and their place in nature is supplied by fresh races.

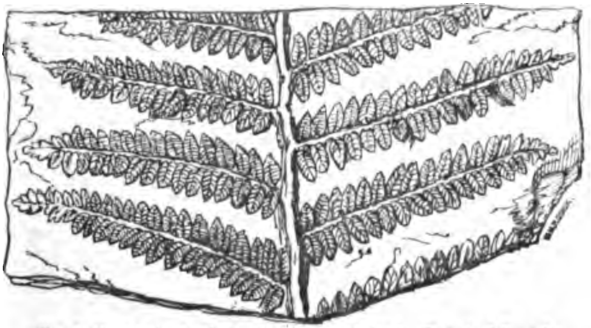

Fig. 6. Pecopteris pteroides. (Half natural size.) (Forest of Dean.)

PECOPTERIS (adherent fern). The name ALETHOPTERIS is given to those species in which the pinnules are long and narrow. The leaflets adhere by their base to the rachis or stem, and are traversed by a strong mid-rib, from which veins branch off almost perpendicularly; some of them simple, some bifurcating, but never intersecting. Sometimes found with fruit patches *(sori)* in the back of the fronds.

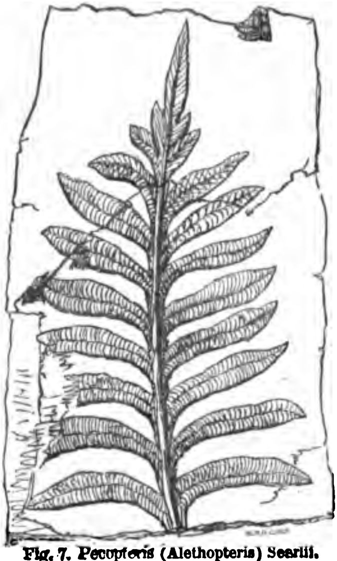

Fig. 7. Pecopteris (Alethopteris) Searlii.
(Half natural size.)

Neuropteris (nerved fern). Leaves more or less heart-shaped and entire, not adhering by their base or to one another; veins very fine, dichotomous, arched as they rise obliquely from the base of the leaflet; bears a general resemblance to the recent *Osmunda regalis*, or royal fern. The leaflets are sometimes so long as to suggest comparison with examples of *Glossopteris*, an oolitic species, and with the recent Hart's-tongue.

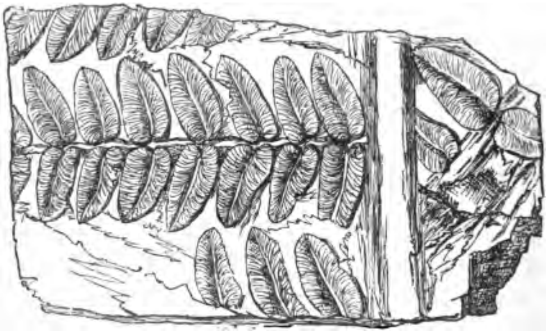

Fig. 8. Neuropteris gigantea. Cwm Avon. (Half natural size.)

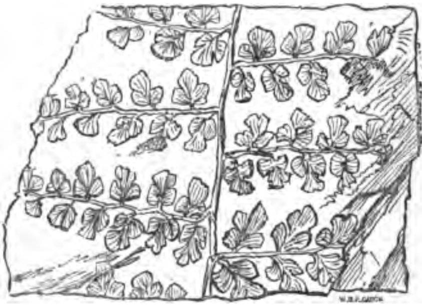

Fig. 9. Sphenopteris latifolia. Felling Colliery Newcastle. (Half natural size.)

Sphenopteris (wedge-fern). Very variable general aspect; leaflets contracted at their base, lobed, and the lower lobes largest, reminding the observer of our recent *Adiantum;* veins on the leaflets radiating from the base.

The ODONTOPTERIS, or tooth-fern, and LONCHOPTERIS, or spear-fern, are genera which occur less frequently than the above.

Some of these fronds appear to have belonged to low plants, others to have grown on large and lofty trees; and certain trunks, called *Caulopteris* and *Palæopteris*, exhibiting clear and frequent scars left after the fall of the fronds, represent the tree-ferns of the carboniferous period.

Lastly we must not omit to mention a kind of plant-remains which have engaged the attention of but few, but which have played an important part in the making up of certain coals.

These are broad, parallel-veined, elongated leaves, referred by authors to very different plants. The most frequent, which were described by Corda as *Flabellaria*, have been since termed *Cordaites*, and have been referred by Schimper to *Cycadeæ;* but they may belong to a lost type of Cryptogams. The vast numbers of them, layer upon layer, visible in certain cases, testify to their having accumulated in thick banks.

No single circumstance about the coal vegetation is more remarkable than its uniformity over a large portion of the world. It has long been known that a great part of the plants of this epoch are alike all over Europe, and even North America. In South America, South Africa, and Australia many of them occur, and at Melville Island, in lat. 76°, and in other boreal spots described by Arctic navigators, similar genera are found.

It has hence been argued that the climate of the globe was at that period more equable; and advancing another step from this basis, the earlier geologists supposed that it was owing to a generally diffused higher temperature—an intermediate stage between the original globe, of fused matter, and our own times, of a cooler crust. But more accurate investigations have set aside this hypothesis, and shown that the general type of the coal flora is that due to a warm—not hot—climate, in which moisture was very abundant. To account further for the inordinately luxuriant growth of the plants which made up the fossil fuel, Brongniart suggested the hypothesis that the atmosphere must at that period have contained a much larger percentage of carbonic acid (poison to animals, but nutriment to plants) than it does now. And when we consider the enormous volume of carbon in the coal and carbonaceous beds, which *must* have been obtained from carbonic acid, and add to it all that which has been locked up since in making the thousands of feet thick of limestone, or carbonate of lime, we certainly have a cause which must have played its part. What were the animals which at this time tenanted the globe, is an interesting but difficult inquiry, when we consider the accidents on which it depends that the remains of land animals should be preserved for our study. The *Archægosaurus* was the first coal reptile found (in Bavaria, 1844), one probably intermediate between the batrachians and the saurians; but the last few years have added several to the list; one of them, the *Dendrerpeton Acadianum*, having been curiously found by Sir C. Lyell and Dr. Dawson in the hollow stump n erect Sigillaria.

ite recently, in November, 1865, Professor Hux- as been able to determine, in a collection of specimens obtained from the Jarrow Colliery, Kilkenny, no less than four, if not five, *genera* of Amphibian Labyrinthodont reptiles.*

Among the other *vertebrate animals* fishes were common enough, their teeth, scales, and spines being abundant in many of the roof shales. Agassiz described above 154 species from the coal-measures, a great part of them predaceous, and stated to be more highly organised than any living fish.

Of the *Mollusca* vast quantities are found, best preserved by being imbedded, petrified, in nodules of ironstone, or flattened in the shales.

In association with the lower seams of coal, in most of our British fields, shells of a decidedly marine character occur. Sometimes one seam, sometimes several, will exhibit in its roof of black shale, and commonly within a few inches of thickness, multitudes of a pecten or comb-shell *(Aviculo-pecten papyraceus)*, and of a curled chambered shell, somewhat like a nautilus *(Goniatites Listeri)*, with rarer examples of *Productus*, *Orthoceratites*, *Lingula*, &c. The bivalve *Anthracosia*, much resembling the Unio, or Horse-mussel of our fresh waters, is sometimes found in the same group of denizens of the sea.

Throughout all the middle and upper measures, the great bulk in fact of the coal-producing strata, *Anthracosia* alone, with some rare exceptions, out of all the above, continues its existence; but this sometimes in such quantities that entire strata ("mussel-bands"), of several inches thick, are made up of them. To these may be added Mr. Salter's genus *Anthracomya*, a mud-burrowing shell, occurring also in dense beds like those of the modern mussel. The black band ironstones of North Staffordshire are literally crowded with them.

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* Eight distinct genera, with indications of others, were obtained by Professor Huxley from this single pit.

And, lastly, through the whole range of the coal strata there may be noticed, either attached to other fossils or embedded in the stone, the minute spiral case of a sea annelid, termed *Spirorbis carbonarius*, and the seed-like valves of a little crustacean, *Cypris*, or *Cythere.* The tracks of large worms (probably marine) occur in great abundance in the clay ironstones which so often diversify the coal shales, and the latter sometimes exhibit the remains of crickets and other insects.

When we pass downwards to the great foundation stone on which our coalfields rest, and with which the lower seams of Scotland and those of Russia are associated, we find, in the carboniferous limestone, a series of strata bearing the most evident traces of marine origin. In part, nothing but banks of corals and encrinites; in others, filled with the well-preserved shells of *Terebratula, Spirifera,* and *Productus,* they tell us plainly of deposits formed in a sea of moderate depth; and since the thickness of these beds varies from 500 to nearly 2,000 feet, it seems probable that the floor of that sea must have been more and more, though not uniformly, depressed. In the period that succeeded—that in which the millstone grit was deposited—there is evidence of much disturbance by sea and land; granite and other rocks broken into bits, or rolled into pebbles, and wafted and dragged about by currents and eddies, whilst an occasional bed of quietly settled shale reveals the shells of *Goniatites, Bellerophon, Lingula,* and other denizens of the sea, who had found a lull, either in place or time, amid the turbulence of the period. And throughout these ta we find the preparatory symptoms, as it were, of the great coal-making epoch that was approaching, in stems and impressions of several of the genera of plants that were soon afterwards so multiplied.

Some years ago there were authors of weight who inclined to the opinion that coal had been formed by the drifting of large masses of vegetable matter into bays or estuaries, and they pointed to the "rafts" of the lower Mississippi as examples of a similar process still in action. But since due attention has been paid to the constant presence of the roots in the floor of the seams, to the upright trunks—often one series above another—and to the high state of preservation of the most delicate remains, it has been generally agreed that most of the appearances are explained by assuming that the vegetation grew on the spot where we now find it.* Some writers there are still who have a hankering after the old aquatic origin, and, supported by the evidence of fishes and marine shells, would assign salt water as a *habitat* for some of the coal plants. But with others the doubtful point is whether the trees and undergrowth flourished on dry land or swampy sea margins. We can no longer doubt that the under-clay was a true soil, in which the great Sigillaroid trees were fixed by their tap-roots, their spreading radical branches, and filamentous rootlets. How many generations of these trees may have risen to maturity and died away before the conditions were favourable to their being preserved, it is hard to surmise; but at length, when a mingled matting of vegetable matter, stems, roots, leaves, &c., had accumulated, like the pulpy mass of a modern peat-bog, the surface of the area was, with much uniformity, depressed. Then would flow back the waters, fresh or salt, over their ancient domain, and, according to the sediment they were able to carry, would deposit sand or mud to be one day known as the rock—or the shale-roof. The *Mollusca* above enumerated then burrowed in the soft ooze, close upon the top of the buried vegetation; in many cases the stumps of the old forest remained standing, whilst mud or silt was deposited around them, until the central portion of the trunk would rot away, serve for a time as an asylum for some of the lizards or land-shells of the period, and then get filled in with petrifying matter. As the water deepened it was haunted by fish of many kinds, whose exuviæ fell to the bottom and were there buried up, and thus bed after bed of sediment accumulated, sometimes to the depth of a few feet, sometimes to hundreds of yards—if the continuous depression of the land was maintained—until circumstances favoured again the formation of a proper soil (the under-clay), and of a growth of trees and plants, when we should have a recurrence of the same phenomena.

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* Franz von Beroldingen appears to deserve the credit of first suggesting the view that the coal-beds are the peat-bogs of a former age, converted first into brown coal and afterwards into stone coal. (Beobachtungen, &c., die Mineralogie betreffend, 1778.) In this theory he was supported by De Luc, and after many years by Schlotheim, Nöggerath, and Lindley and Hutton.

An enormous bulk of vegetable matter would be needed thus to form one of our thicker seams of coals; but we have seen how the latter are generally divisible into several beds, and these again into thin laminæ, whilst we know that peat-bogs of the present day, without the special advantages of the coal jungle, attain depths of 30 or 40 feet. It has been estimated that eight feet thick of packed woody substance would be needed to make one foot of coal; but we may take it for granted that such an amount would represent only a fraction of the total amount of vegetation that flourished at the time, since much of it must doubtless have escaped from the preservative process of interment.

We cannot afford space to dwell on the chemical argument by which this derivation of the different kinds of coal is shown to be probable; but the following table, borrowed from Dr. Percy's "Metallurgy," supplies at a glance an illustration of the successive steps in the change from woody tissue to anthracite. The porportions of carbon in each substance being taken at the constant amount of 100, the hydrogen and oxygen will be found to have been more and more eliminated.

	Carbon.	Hydrogen.	Oxygen.
1. Wood (mean of 26 analyses) . .	100	12·18	83·07
2. Peat	100	9·85	55·67
3. Lignite (average of 15 varieties) .	100	8·37	42·42
4. Ten-yard coal, South Staffordshire	100	6·12	21.23
5. Steam coal from the Tyne . . .	100	5·91	18·32
6. Pentrefelin coal, South Wales . .	100	4·75	5·28
7. Anthracite, Pennsylvania . . .	100	2·84	1·74

When the buried forest had once been fairly covered up by hundreds, and as the land sank, by thousands of feet of rock, we may conceive it subjected to those conditions of pressure, temperature, and moisture, which were needed to change it into that condensed form of fuel now so necessary to mankind.

And when at length, after ages of due preparation, portions of the coal formation were upheaved into the islands and continents, the seams of coal were brought into a position to be accessible to man, and the forces of the sunbeams, which fell upon the jungles of the primeval world, are again unlocked and made subservient to our use, when we now decompose by burning those compounds which had been called into existence by the solar light and heat.

CHAPTER IV.

COALFIELDS OF THE NORTH.

IN order to enable us to form a due estimate of the coal resources of the various countries, we must glance at the extent and character of the coal-measures as they are developed in the different districts; and since the history and commercial importance of the coalfield of Newcastle give it the pre-eminence, we may conveniently start from that focus of activity.

It must be premised that the limits of a coalfield are not to be confounded with the area coloured as "coal-measures" in a geological map; for although in some regions (as in South Wales) it is one and the same thing, the coal-seams are often well known and largely worked beneath other newer formations, which in a map are represented by their proper colour, whether they overlie coal-measures or any other older rocks. We shall, therefore, in many instances have to speak of a coalfield as such, where it signifies the extent of proved coal-producing ground, whatever the mere covering may be composed of.

On examination of a geological map it will be seen that, coming southward from the Durham coalfield on one side of the central chain of North English hill country, and from that of Cumberland on the other, a large interval separates them from those of Yorkshire and Lancashire respectively. It will be seen, too, that there are certain features of connection in each case between the East and the West, which it is not so easy to establish between North and South, and we may therefore take one division for this chapter as including the coal regions north of a line drawn from the mouth of the Tees westward through Kendal and the south side of the Lake country.

About equidistant from the Irish Sea on the west and the North Sea on the east rises the broad backbone of the hill country, composed of the carboniferous limestone with all its numerous subdivisions so carefully studied by the lead-miners of those breezy fells, and bearing on its culminating points, and on the high ground extending for many miles breadth on the east, a capping of millstone-grit. On the west side, or towards Penrith, this main chain has been greatly disturbed and abruptly broken at an early geological period, whilst on the other side the land slopes more uniformly from the high ground. The strata here, inclining gently eastward, partake of the same regularity, and as we proceed towards the coast, succeed in ever ascending order till the various coal-seams "put in," one after the other, and are at length similarly capped by the magnesian limestone, and soon afterwards—not cut off, but surmounted—by the sea. The field of the Blythe, Tyne, and Wear, so-called after its rivers, extends from the Coquet on the north to near the Tees on the south, for about 50 miles in length, with a breadth of about 20 miles for a great part of the way, till it narrows to a point when it passes north of the Blythe, an area in all of 705 miles. For some miles in breadth along the western side, only a few of the lower seams are worked; then, in a line ranging through Newcastle and Durham, we get the full number of the workable seams; and again, following a sinuous course from Tynemouth past Houghton-le-Spring to near Bishop Auckland, the overlying permian formation succeeds, represented by a generally bold outline of magnesian limestone resting on the irregular lower red sand, which, from its water-bearing and loose properties, presents great difficulties to the sinking of shafts eastward of this line.

In former days this upper was confounded with the lower (carboniferous) limestone, and it was supposed that a limit was thus formed to the coalfield on either side. It was, therefore, a bold step, when the Messrs. Pemberton, relying on true geological reasoning, determined to pierce downward from the coast near Sunderland, and search for the hidden coal-measures below. Their famous Monkwearmouth pit was commenced in 1826, and had to pass through 330 feet of this newer formation, towards the bottom of which no less than 3,000 gallons of water per minute had to be raised by pumping power, until it was successfully tubbed off. At 285 fathoms depth they cut the Hutton seam, having previously intersected the Maudlin or Bensham seam 20 fathoms higher. And these results appear to establish a curious point in the configuration of the coalfield. The seams which thus lie nearly 1,700 feet below the sea at Sunderland occur at a less depth as they pass to the north and to the south, whilst westward they rise to their outcrop at Howes Gill—an elevation of 740 feet *above* the sea, giving a difference in level of 2,440 feet. It would appear, then, that this is the deepest part, or a sort of transverse trough in the stratification; but as the measures have generally a gentle inclination eastward, where they have been sunk to along the coast, it yet remains to be proved whether the deeper part of the entire basin does not lie further seaward, and the probability remains of a large area of this productive coalfield extending beneath the German Ocean. At these deep pits, and those of Ryhope and Seaham, also sunk within the last few years at a small distance from the coast line, the deeper seams of the field have not yet been reached; but from sections obtained in the shallower pits in the west, the succession is perfectly well known.

The total thickness of the measures from the lowest known seam upwards may be taken at little more than 2,000 feet. The upper half contains only a few unworkable beds, the lower half all the valuable seams. In this field, as in all others, the thickness and character of a particular band of coal will be found to vary, and that to such an extent as to occasion much difficulty in identifying the seams of distant pits. A coal which is suitable for steam purposes in one part of the area, will be more fitted for household use in another; and that which is the mainstay of a colliery in one locality may be barely traceable in another.

The chiefly important seams are the following:—

		Feet.	Inches.
Monkton and Hebburn Fell seam		2	10
High main		6	0
Metal coal		3	0
Yard coal (Main coal of Hetton, 6 feet)		3	8
Bensham or Maudlin, 4 feet 8 inches at Monkwearmouth		6	0
Six-quarter		2	6
Five-quarter (Low main at Monkwearmouth)		4	1
Low main (Hutton seam 4 feet on the Wear)		6	0
Crow coal, generally thin, at Ryton		2	3
Five-quarter		3	8
Ruler		1	6
Townley main		3	10
Stone coal, or five-quarter	Busty Bank.	3	9
Six-quarter		3	4
Three-quarter		2	6
Brockwell		3	2

The average number of seams found to be workable in any one section may, I believe, fairly be taken as twelve, with about 50 feet of coal in the aggregate.

Great advantages exist in the district: first, in the general regularity of the measures, dipping at a very moderate angle, commonly about 1 in 20; the convenient thickness of the seams, from 3 to 6 feet; the excellent qualities of the coals, and the usual goodness of the roof, which allows of wide working places and roads, with a very small expenditure of timber. The difficulties are the considerable depths of the sinkings in the newer pits, the watery strata to be pierced, and the large amount of fire-damp giving off by many of the seams.

Faults or slip-dykes are few and far between as compared with most coalfields, and the *whin* or basaltic dykes, which traverse the district in an east-south-east direction—although they injure the coal on both sides of them to a distance of some yards—are not found to derange and interfere with them as they do in Scotland and South Staffordshire. Among the ordinary faults, the most remarkable is the great 90 fathom dyke, which—appearing on the coast near Cullercoats, where it displaces the strata to that amount—ranges past Gosforth to Blaydon, and then entering on the more hilly ground, may be traced westward through the limestone range to the new red sandstone in the neighbourhood of Carlisle. Along this part of its course the *throw*, though variable, is sufficient to inlay, as it were, on its north side a long strip of coal measures, and thus to give rise to the collieries of Stublick, Midgholm, Tyndal Fell, &c.

The variations in quality of the seams as they range through this extensive field give rise to different commercial applications. The best "household coal," commonly called after the well-known *Wallsend* pits, extends from the Tyne to the Wear, and from the last-named river to Castle Eden, and occupies another area about Bishop Auckland. The denser white-ash steam coal characterises the district beginning some five miles north of the Tyne; whilst the tender coals, which afford an admirable coke, are largely worked all along the line of the outcrops on the west, from Wylam and Ryton down to the outskirts of Raby Park.

The total production of the Durham and Northumberland field, which, in 1854, was 15,420,615 tons, is for the year 1864 no less than 23,284,367 tons.* This enormous increase is in great part due to the rapid development of the Cleveland iron district, in North Yorkshire. The iron furnaces in the three districts fed with the coal from this field were, in 1854, as many as 58; in 1865 they were augmented to 105 actually in blast; and as huge quantities of Durham coke are now conveyed to the western coast for the smelting of the hematite ores, the total quantity of coal thus consumed is probably much more than doubled in one decennium.

CUMBERLAND COALFIELD.—In the mountain limestone district about Alston, two or three small seams of anthracite (*crow coal*), mostly of but a few inches thick, have been worked for lime-burning, &c., yet are of little commercial importance. But a remarkable change occurs on their passing the great *dyke*, or fault, above described; for on the line of the Newcastle and Carlisle railway one of them has been worked at Blenkinsop, of good bituminous character, and no less than 6 feet thick, surmounted by a limestone roof. As these seams pass northward they increase in number and importance, till in the farther parts of Northumberland they are described by Mr. Boyd as being twelve in number, from 2 to 4 feet each; and thus it is that they form an introduction to the series of limestone coals so valuable in Scotland.*

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* In 1870, 27,613,539 tons. In 1878, 30,133,884 tons.

On the western side of the great limestone chain slight indications of much-disturbed coal-seams occur near the base of the great Cross Fell escarpment; but the important part of the Cumberland coalfield only appears distinctly on emerging from beneath the red sandstone cover, south of Wigton, whence it laps round the older rocks of the Lake District, by Maryport, Workington, and Whitehaven, to its termination, near St. Bees.

The total thickness of the measures, as well as the number of seams, is notably less than in the Durham field, whilst its length is under 30 miles, and its proved breadth about 6 miles. The quality is also inferior for household coal, and very much so for coking. Certain of the seams are, however, remarkable for thickness and regularity, as well as the peculiar circumstances under which they have been worked. These are best exhibited at Whitehaven, where along a coast line of nearly 2 miles extensive operations have been carried on by Lord Lonsdale to the distance of 2 to 3 miles under the sea. The strata here dip slightly seaward, but are intercepted by a numerous succession of faults which have rendered their exploration unusually difficult and expensive. Fortunately, the dislocations have been of such a character as to allow of this large area being mainly worked by horizontal roads driven off from the William, Wellington, Croft, and Saltom pits, at depths of from 100 to 150 fathoms. The principal seams (omitting two or three thin beds above and below) are as follows:—

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* See Mr. Boyd's paper in the Transactions of the Institute of Mining Engineers.

Bannock band, 6 ft. 4 ins. to 10 ft. 11 ins., including 14 ins. to 3 ft. 6 ins. of "metal" partings.
Strata 20 fms.
Main band, 9 ft. to 11 ft. 9 ins., with occasional partings of 2 ins. to 1 ft. 3 ins.
Strata 40 fms.
Six-quarter band, 4 ft.

In the year 1765, M. Jars states that operations had already been extended to the distance of a quarter of a mile under the sea; that three seams were in work: an upper, rather stony, 5 feet coal, used for salt-making; the second, 75 fathoms deeper, the Bannock band; and the Main band of 10 feet thick. Wooden rails were in use, and the drainage was effected by four fire-engines, two of which stood on the sea-shore. Fire-damp appears to have been very troublesome, and it is a remarkable fact that the manager of the mine had at that early date proposed to the authorities of Whitehaven to lead pipes through all the streets of the town to light them at night with the natural gas.

At Workington the seams were also wrought beneath the sea, but as they rose towards the bottom of the sea, they were followed up too far, and as due precaution was strangely disregarded, the sea burst in in 1837, and the lamentable result was the loss of thirty-six human lives, and the entire destruction of the colliery. The same seams are extensively worked on their rise at the Clifton and other collieries in the valley of the Derwent, and again towards Maryport and Wigton.

The total production of this county has increased from 887,000 tons in 1854 to 1,408,935 tons in 1870.*

COALFIELDS OF SCOTLAND.—In tracing northwards the great calcareous mass which forms the mountain limestone of Derbyshire and Yorkshire, we have seen above that when it enters Cumberland and Northumberland it has already greatly changed its character. Divisional strata of shale (*plate*) and sandstone (*hazel*) separate the bands of limestone, and coal seams make their appearance, which, beyond the great 90-fathom dyke, attain considerable technical importance. And when at length we cross the border, and enter upon the Scottish area, we find this formation—lapping round the great upheaved districts of older rocks ranging from Kirkcudbrightshire to Berwick—to contain a valuable and largely-worked series of coal-seams.

The range of the carboniferous formation in Scotland extends from the coast of Ayr to the mouth of the Frith of Forth, and over an irregular width of from 20 to 30 miles; but as regards the workable portions it is broken up into several distinct fields, partly by the uprising of the lower coalless strata, and partly by the interference of vast masses of igneous or trap rocks (the whin of north England), sometimes bedded, and at others injected as dykes.

The full thickness of the coal-bearing strata is well shown in the coalfield of Midlothian, east of Edinburgh, where a district of about 9 miles long by 2 or 3 miles wide, is occupied by "measures" perfectly analogous in character and contents to the English coalfields.†

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* This amount was not exceeded in 1878.

† See Mr. Milnes' account of this coalfield in the Trans. Roy. Soc. Ed., and Mr. Howell's description in the Memoirs of the Geological Survey, 1861.

In a total amount of about 1,200 feet, including a middle band of 200 feet of unproductive rock, are developed some twelve seams, mostly from 2 to 5 feet thick, although one of them, the "great seam," attains a thickness of 8 to 10 feet.

Below these comes the millstone grit, of 340 feet thick, and then in descending order the carboniferous limestone, with a total thickness of 1,590 feet, but containing, along with only some 40 feet of limestone in many thin bands, a series of about seventeen beds of coal of from 2 to 5 feet each (Howell).

The lower limestone is without coal.

Mr. Matthias Dunn, writing in 1830, gave an interesting description of the working of the outcrop or edge coals, which, in a measured section at Niddrie Colliery, he states to be twenty-four in number, workable seams, with a total thickness of 95 feet of coal in 4,344 feet of measures, included between the "gramacham" or "diamond" above, and the "north greem" seam below, which rests nearly upon the thick encrinital limestone.

The Fifeshire coalfield, as described by Mr. Landale, presents a valuable array of seams, one of which—the Dysart main seam—attains the unusual thickness of 21 feet; but this region is much dislocated by faults and interfered with by igneous rocks.

Passing westward through Clackmannan, Stirling, and Linlithgowshire, we come to the important fields of Lanarkshire and Ayrshire, where the chief features are the admirable gas or parrot coals, the moderately-thick splint coals, used for iron-smelting, and the black bands, or beds of carbonaceous ironstone, which have for many years been the mainstay of the surprising production of Scotch pig-iron. Mr. Ralph Moore, adopting a similar three-fold division to that above cited, states the general character of the section to be—

1. The true coal-measures, 840 feet, from the upper 4-foot coal down to the slaty-band ironstone, including ten seams of 2 to 5 (and in one case 8) feet in thickness.
2. The millstone grit, 960 feet.
3. The limestone series, 2,200 feet, with three beds of black-band ironstone, and several seams of good coal.

The importance of the coalfields of Scotland may be inferred from the fact that in 1854 the production of coal was 7,448,000 tons, from 367 collieries; in 1870, 14,934,553 tons, from 411 collieries.*

CHAPTER V.

COALFIELDS OF CENTRAL ENGLAND.

If the reader will take in hand a geological map of England,† and fix upon the curious rugged hill of Mow-Cop, near Congleton, as his centre, he may draw a circle with a radius of 60 miles, which will embrace sixteen patches of coal-measures, being fields and basins more or less separated from one another. Geologically, we have very good reasons for assigning a common origin to the whole of them, and considering them to be the separately visible portions of one vast deposit, which, in the course of ages, has variously been depressed and covered up by newer strata, then upraised and denuded in part, so that—after the fashion of Virgil's famous oak-tree—whilst the higher portions may have stood 8,000 feet above the crests of the Peak of Derbyshire, the lower beds approximate to Tartarus by dipping down from off the Buxton moorlands to a depth of some 12,000 feet beneath the plains of Cheshire. And the inductions of geology in this respect will at no distant day be required to solve a question of national moment—the continuity and position of the coal-measures between these apparently disjointed fragments.

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* In 1878, 534 collieries produced 17,837,282 tons.

† It has been thought unnecessary to insert a map in this little volume, when so many good geological maps on a useful scale are before the public. As a series arranged according to increasing size, may be recommended Sir Rod. Murchison's little map prepared for the Society for the Diffusion of Useful Knowledge; Prof. Ramsay's England and Wales; Knipe's British Isles; and Greenough's large map, edited by the Geological Society.

YORKSHIRE AND DERBYSHIRE.—From Leeds to Nottingham there extends an unbroken range of coalfield, 65 miles long by from 8 to 20 miles wide, inclining on the whole gently to the east, where it is covered in succession by the lower red sand, the magnesian limestone, and the new red sandstone. Whilst, therefore, bounded on the west by the outcrop of the beds, it is on the east only overlaid by newer formations, and in all probability extends far beneath them.

The thickness of the measures where fully developed (which is not the case until some miles away from the outcrop) is about 3,000 feet, out of which the lower several hundred feet are chiefly noticeable for the occurrence of flagstones, and of coals with ganister floor, whilst the shales contain the marine shells, already enumerated at p. 39. The chief seams of coal and ironstone are found in greater number towards the bottom than the top of the measures, and the former may be taken on the average at sixteen in number, with 45 feet total thickness of coal. The most remarkable of the seams is the "top-hard," which, in Derbyshire, is 5 to 6 feet, but increases on passing into Yorkshire, till it becomes the "Barnsley thick bed," of 9 feet. Another seam, now well known in the London market, is the "Clod" or "Black Shale" of Derbyshire, the "Silkstone" of South Yorkshire; and one of the purest house coals ever seen is the "Kilburn coal," a bed only developed in the south of Derbyshire.

In these counties, then, with the adjoining Nottinghamshire, we have the largest continuous coalfield in England; for we may estimate that it occupies about 800 square miles. But one of its most welcome features is its prolongation eastward, first proved on the large scale by the Duke of Newcastle's spirited sinking at Shireoak, where—commencing in the red sandstones at the distance of five miles from the visible coalfield, and cutting the top-hard coal at 510 yards deep—it is not only shown that all the measures are in their proper place, but that they may be expected to lie at moderate depth and an easy inclination. It may be roundly said that this success assures us of half as much again to be added to the resources of the coalfield, and a speculative mind will reckon on a still larger augmentation.

LANCASHIRE.—More irregular in form, and much intersected by great faults which dislocate the strata to the amount of hundreds of yards, this coalfield is one of our noblest. Crossing to the westward the ridge of lower rocks which separate it from Yorkshire, a watchful eye will recognise the re-entry into the ground of the various seams which had been seen to pass out on the opposite side of the hills. Especially is this to be noted with the Ganister coals, and the peculiar fossils in their roofs, and with the Arley *mine* or seam, which occupies the place of the Black Shale or Silkstone.

As a general feature, although much interfered with by the great dislocations, the analogous arrangement to that of Yorkshire is observable, viz., that the seams incline off from the high country of the moorlands, and are succeeded, after occupying a variable breadth of surface, by the newer beds of the Permian and Trias formations. But the total thickness of carboniferous strata, as well as the number of coals, is much greater than on the eastern side of the chain of hills.

Mr. Binney, the assiduous explorer of this field, has long since found it convenient to divide its thickness of above 7,000 feet into three portions, as follows:—

1. Upper coalfield, including the peculiar Ardwick limestones, with numerous fish-remains, and several thin beds of coals.
2. Middle coalfield, 3,500 feet, containing all the more important seams from the Worsley four feet downwards.
3. Lower coalfield, or Ganister series.

The chief centres of activity are St. Helens, Wigan, Chorley, Bolton, Manchester, and the outlying tract of Burnley. The seams are generally from three to six feet thick; one of the most noted is the excellent Cannel of Wigan, three feet, sometimes occurring in close proximity to the "King-coal;" and here, as at Pendleton, Patricroft, &c., near Manchester, very extensive collieries are worked at depths of from 400 to 600 yards.* The total number of seams above two feet in thickness is on the average 16 to 20, with about 70 feet of coal in the aggregate, whilst the entire area is given by Mr. Hull, who has examined it for the Geological Survey, as being 217 square miles.

CHESHIRE.—The Lancashire is continuous on the south and east with the Cheshire coalfield, so that a narrow strip belonging to this latter county exhibits a very similar succession of strata. A special interest has been given to its mining by the fine shaft (the deepest in England but one) sunk by Mr. Astley, at Dukinfield, to the "Black Mine," at the depth of 686 yards; and pierced through no less than 22 workable coals. Towards Congleton this coalfield fines off, and is divided by a very narrow interval from that of

NORTH STAFFORDSHIRE.—Here a very singular plication or folding of the strata brings in a most valuable succession of coal-measures, amounting in the whole to about 5,000 feet in thickness.

1. The *upper portion* of 1,000 feet contains a quantity of red and purple clays, much used in the potteries for bricks, &c., and only a few thin coals.
2. *Pottery coals and ironstone measures*, 1,000 to 1,420 feet, with 8 to 13 seams of coal of above two feet thick, most inferior; and 10 to 12 measures of ironstone.
3. *Lower thick measures*, containing the chief furnace coals, from the Ash to the Winpenny inclusive, 17 or 18 seams above two feet. Ironstone scarce or absent.
4. *Lowest measures*, 800 feet, with from two to four thin coal seams.

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* The Rose Bridge Colliery, near Wigan, is 815 yards deep.

Neglecting the seams under two feet in thickness, we have in certain measured portions of this field no less than 40 seams, with a total thickness of 140 feet of coal; in another case 24 seams, with 109 feet. Among its more remarkable beds are the courses of carbonaceous ironstone, or black-band, which occur three or four in number, with a variable thickness, but amounting in some cases to three, four, and even six feet, often crowded with shells of the bivalve *Anthracomya.* Near these also comes in a thin band of fresh water (?) limestone, containing *spirorbis carbonarius,* and analogous to the Ardwick limestones near Manchester, and to a bed with the same fossils in the coalfield south of Shrewsbury, and in that of Warwickshire.

The boundary on the eastern side of the tract is the outcrop, against the bleak hills of millstone grit; on the west the new red sandstone, under which its beds plunge; and on the south an irregular line, occasioned by dislocations and the inletting of the overlying Permian strata.

A small outlying field, named after the town of Cheadle, with seven or eight seams, is of very limited importance.

Taking your stand on the high ground on the west of the Potteries coalfield, you may, on a clear day, descry the Shropshire field on the south, and the Welsh hills on the west, with the coal area of Denbighshire at their base. The plain of new red sandstone and marl exetnds almost like the sea from one hill range to the other, and the idea involuntarily suggests itself to the mind of the geologist that the coal-measures are continuous beneath those broad intervals, even though the depth may be such as to render them, in part at least, unattainable to man.

DENBIGHSHIRE AND FLINTSHIRE.—Commencing suddenly with a bold promontory of the carboniferous limestone near Oswestry, a band of coal-measures reposes against the chain of hills which course by way of Ruabon and Mold to Mostyn, at the mouth of the Dee. The seams are not numerous, but some of them, as the 3-yard and 5-yard coals, are remarkable for their thickness; and a bed of cannel, lately found near Mold, is no less noted for its excellent quality. Moreover, the boundary of the field being, on the east and north-east, the overlying new red formations, leaves it very probable that a large amount of coal, continuous with that already worked, may be found at moderate depths.

SHROPSHIRE. — Omitting some small unimportant patches of coal around Shrewsbury, we arrive—in the Coalbrook-dale district—at a focus of colliery working intimately connected with the development of the British iron-trade. The total thickness of the measures is but 1,000 to 1,200 feet, and the number of seams of coal with their height also diminish rapidly in going south, so that the 55 feet of coal at Donnington dwindles to 40 feet at Lightmoor, and to 16 feet at Amies, near Broseley, south of which town all the ironstone measures—so valuable north of the Severn—are represented by a single bed—the Crawstone. The especially interesting geological characters of the district have been excellently described by Prestwich (Geol. Trans. 2nd Ser. vol. v.), and further details on the ironstones are given in "The Iron Ores of Great Britain" (Mem. of Geol. Survey, 1862).

The whole of the old or hitherto-known coalfield will in a very few years hence be entirely exhausted; but already successful workings have been put through the Permian rocks which border its eastern margin; and the geologist has little doubt that were he possessed of physical penetrating power enough to enable him to dip with the coal-seams as they incline eastward, he would, after a deep underground passage of some 14 miles, emerge again in the coalfield of

SOUTH STAFFORDSHIRE AND WORCESTERSHIRE.--The "black country," as it has been popularly called, exhibits the most amazing focus in the world of the various manufactures which depend on a plentiful supply of coal. Its mingled forges, pit-heaps, engines, canals, railways, and blast furnaces, and the roar of activity which pervades the district, create in the visitor a feeling of confusion, which only gradually subsides into admiration of the great natural advantages conferred by the contents of the substrata,—advantages which have been the means of attracting a dense population, and of raising upon and around it a vast assemblage of various and prosperous branches of industry. The total area is not large—about 90 square miles—and the total thickness of measures moderate—say 1,800 feet; but the presence in the southern part of the field, about Dudley, Bilston, and Wolverhampton, of the 10-yard coal (from 24 to 36 feet thick) has been a feature of importance without a parallel. The roughness of the surface has been repeated below ground, and the mode of working this admirable deposit of fossil fuel has been a model of which we have no reason to be proud: sad loss of life and great waste of coal having characterised it almost throughout; and the rapid exhaustion of the present pits renders it probable that in a few years the workings of the "thick coal" will be matter of history.* Meanwhile the lower seams of the "Heathen" and "New Mine" coals are coming into great employ, and a comparatively new field of many different seams—the separated representatives of the 10-yard coal—has been rapidly opened out in Cannock Chase. For the details of this coalfield we must refer the reader to the excellent description by Mr. Jukes, "Mem. Geol. Survey," 2nd ed., 1859.

The number of seams may be given as averaging six, with a total thickness of 50 feet of coal.

Two peculiarities of this coalfield require to be mentioned, even in a brief sketch like the present. 1st, the prevalence of intrusive dykes and bands of igneous rock, the *white* and *green rock* of the miners; and 2ndly, the absence of the millstone grit and carboniferous limestone, the coal-measures reposing directly upon the silurian shales and limestone.

The glory of South Staffordshire as an independent district is past; but the iron-masters make a gallant fight of it in competing with other districts by the introduction from great distances of cheaper iron-ores as well as coals, and by strict attention to the quality of their products.

WARWICKSHIRE.—On the south-east of Tamworth, the clearing away of the red marls reveals a coalfield, which runs for some 15 miles in length by Nuneaton and Atherstone, in the same south-easterly direction as the Trent-Valley Railway. The total thickness of its constituent rocks is nearly 3,000 feet; but the lower half is unproductive, and the upper half contains only five seams, with an aggregate of 26 feet of coal.

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* The discovery at Sandwell Park, in the last few years, of a new area under the Red Sandstone is highly important. 1880.

The area, too, being only 30 square miles, leaves this a very unimportant tract at present; but its significance as an indication is not to be overlooked, seeing that, like the last and next following coalfields, it is surrounded for the most part by the new red formations, and may, therefore, with confidence, be expected at a future day to be greatly extended.

LEICESTERSHIRE.—In this county—again after an interval of a few miles of the covering of red rocks—a coal-producing tract presents itself. With a total amount of strata a little less than the last, it exhibits more seams, generally ten of workable thickness, with 45 feet aggregate of coal. The Moira Colliery, near Ashby-de-la-Zouch, is very largely opened on the fine "main seam" of 12 feet thick, of which only the upper six feet, the *over coal*, is taken out in the present operations; the *nether coal*, of rather inferior quality, remaining for a future day.

The actual area of the denuded coalfield is only 15 square miles; but several pits have already been sunk with success beyond its boundaries through the overlying strata.

It will be interesting to compare, for the above districts, the production of coal during 1864 with that of ten years before, and with the later statistics.

	Produce of coal in 1854. Tons.	1864. Tons.	1870. Tons.	1878. Tons.
Yorkshire	7,260,000	8,809,600	10,606,604	15,588,810
Derbyshire	2,406,696	4,470,750	5,102,265	7,190,000
Nottinghamshire . .	813,474	796,700	2,115,372	4,107,350
Lancashire	9,080,500	11,530,000	13,810,600	18,060,025
Cheshire	786,500	822,750	929,150	616,575
Shropshire	1,080,000	1,150,000	1,343,300	830,575
Staffordshire and Worcestershire .	7,500,000	11,459,851	13,230,062	13,203,190
Warwickshire . . .	255,000	754,000	647,540	1,025,450
Leicestershire . . .	439,000	890,500	599,450	1,020,500
North Wales . . .	1,143,000	1,987,060	2,329,030	2,222,357

The ratios of increase in ten years in the different counties are remarkably unlike; and whilst in most cases the quantity raised has been augmented by from 20 to 60 per cent., in a few of them it has been more than doubled. The numerous canals and railways of central England greatly increase the mutual connection of these several fields, and as time advances, new bore-holes and sinkings will ere long throw additional light on their natural relationship.

CHAPTER VI.

COALFIELDS OF THE WEST OF ENGLAND, SOUTH WALES, AND IRELAND.

Bristol and Bath.—A large area, extending for some 25 miles in length from the Mendip hills on the south, and closing to a point near Wickwar, consists of coal-measures exposed to the surface in large patches, but covered over much of their extent with the newer formations—red sandstone, lias, and oolite. On the southern, western, and north-eastern edges the coal-bearing strata repose on the carboniferous limestone; whilst their eastern termination, where they pass under the Bath oolites, is at present uncertain. The total thickness of the series, above the millstone grit, or "Farewell rock," is about 5,000 feet; but except over certain small portions of the ground, the upper part of the series, containing some of the best household coals, has been swept away by denudation prior to the deposition of the red rocks. Thus, in the rich district north-east of Bristol, the uppermost seams appear to be absent, whilst in the neighbourhood of Radstock and Midsomer Norton a very interesting basin-shaped deposit of them is explored by the collieries of H.R.H. the Prince of Wales and of Lady Waldegrave. These seams are already deep at some of the pits; as for example, 200 fathoms at Clandown (where 40 fathoms are sunk through overlying formations), and above 100 fathoms of barren strata intervene before another group of coal seams is arrived at. The second group occupies, of course, a much larger area than the first, and is worked at Farrington Gurney, &c. Next in order comes a great thickness of sandstones, termed the "Pennant," which occasionally present the rough structure of millstone grit. Below the Pennant we have again a deep series of shales, containing a considerable number of seams, some of which are worked at Bedminster, Stratton-on-the-Fosse, &c.; whilst the lowest coals, very close to the limestone base, are worked at Vobster, Ashton, and at Nailsea.

It is observable that the mode of working adopted in the southern part of this district, coupled with certain local advantages, has rendered it possible to work coal seams of little more than one foot thick; nay, in one of the "little veins," I have measured the height to be only 11 inches of coal! We may, therefore, take a comparatively greater number of seams in this field to be "workable," and it would appear that they may be grouped as follows:—

Upper series, Radstock, 6 seams, with total of 11 to 12 feet of coal.
Second, or Farrington series, 4 workable seams, with 6 to 12 feet of coal.
Pennant grit, with thin seams, 1,500 feet.
Third series, Bedminster, Stratton-on-the-Fosse, } 20 to 36 seams, with
Lowest series, Vobster, Nailsea, &c., } 60 feet of coal.

The last two groups are not very distinctly separated, and their seams are difficult to identify, from their being variable in character and being much disturbed where they approach the limestone. Indeed, the vertical and even overthrown condition of the strata at Vobster, on the north flank of the Mendip hills, is our nearest approach, in Great Britain, to the abrupt foldings which are so remarkable in the coalfields of Belgium.

When we look to the numerous and thin seams of the south portion of this field, and the violent contortions to which, along with their limestone base, the coal strata have been subjected, we are induced to recognise the Belgian type, and to look eastward, in the direction of the axis of disturbance, for a continuation of the trough of coal-measures. Evidence, however, not altogether conclusive, has been obtained by boring, which would make it probable that the lower measures also, like the upper ones, crop up under the overlying rocks. Towards Bath, at Twiverton, seams of the lower series, much faulted and highly inclined, are worked, but it is uncertain how far they extend. We may also speculate on the coal-measures being brought in again by convolution on the south side of the Mendips, beneath the more recent formations; but on this point no trials appear to have been made.

It may be remarked, that a source of error in estimating the quantity of coal in the ground is very observable in parts of this field; viz., that certain tracts of the good seams have been so faulted and squeezed by natural causes as to yield little else than slack, and thus to be commercially valueless. And a notable peculiarity is met with in the *overlap* faults at Radstock and Clandown, where the seams are dislocated by slides in a direction opposite to the usual one, and are thus doubled over themselves, so as to give, over a breadth of from 50 to 200 and even 300 yards, a double tract of the same coal.

FOREST OF DEAN.—This complete and picturesque little coal basin, clothed in great part with fine oak forest, is an admirable study for the student,—dipping on all sides towards the centre, and skirted by its base rock, the carboniferous limestone. It is about 34 square miles in extent, and from its regularity is thoroughly known, even where as yet unproved by pits.*

The coal measures are about 2,300 feet thick, and contain, principally in their lower part, eleven seams of 18 inches up to 5 feet high, giving a total thickness of about 27 feet of coal.

Below the Churchway, and above the Coleford High Delf seam, there occurs a thick series of sandstones, giving rise to numerous excellent quarries, and which in some degree appears to be equivalent to the Pennant of the Bristol field.

Several of the coals about the middle of the series are remarkable for the great number and variety of fossil-plant remains found in the roofs: whilst the lowest thick coal, the Coleford Highdelf, from 4 to 10 feet 6 inches, shows only sigillariæ and other large obscure trunks of trees. Ironstones are almost entirely absent, but the want of them is amply made up for by the admirable brown oxide of iron found abundantly in

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* A beautiful model, showing most instructively the position of the various seams, was constructed some years ago by Mr. T. Sopwith, F.R.S., and was deposited by H.M. Commissioners of Woods and Forests in the Museum of Practical Geology, Jermyn-street.

churns or irregular deposits in the upper portion of the limestone.

The Dean Forest field produced in 1854, 420,866 tons of coal; in 1870, 907,183; in 1879, 779,428 tons.

DEVONSHIRE.—In the north of this county, the neighbourhood of Bideford is remarkable for the occurrence of small seams of anthracite, or *culm*, which have been worked to a considerable extent. They are of but small commercial importance, but are interesting as offering a parallel to the thin seams found in the large tract of carboniferous slate in the south-west of Ireland.

SOUTH WALES.—The magnificent coalfield which extends from Pontypool on the east to St. Bride's Bay on the west, and occupies some 900 square miles, chiefly in the counties of Monmouth, Glamorgan, and Carmarthen, is no less remarkable for its thickness than for the variety and excellence of its products. Based upon a foundation of bold hills of limestone, which rise on its northern, southern, and eastern limits, it forms through a great part of this length an elongated basin, containing a mass of picturesque hilly land, intersected by numerous streams, which have a mainly north and south direction, and in which the greater number of the works are situated. The very numerous dislocations by which it is intersected follow a still more regular meridional course. The great breadth of the field, from 12 to 16 miles, and the rapid inclination of the strata, would soon carry them down to unattainable depths, but for their being again raised nearer to the surface by an axis of elevation, or *anticlinal* ridge, which is traceable along a considerable distance in an east and west direction.

In Monmouthshire the thickness of the strata is far less than in the more western portion, and the maximum depth to the lowest important seam (the Black Vein) may be estimated at 650 yards, whilst the lowest workable coal would be reached at 750 yards from the surface in the valleys.[*] Here the uppermost notable seam is the well-known house coal, the Mynydd Isslwyn, 5 feet 6 inches, which, occupying only the middle of the trough, has already been worked out over a great part of its area. Beneath this comes a great thickness of sandstones, the "Pennant;" and below that again the measures, including the excellent furnace-coals and clay iron ores, which have given rise to the great ironworks of Pontypool, Ebbw Vale, Tredegar, &c.

Farther west, the sandstones are greatly augmented in thickness, and are surmounted by a series of measures with many workable seams, which appear to be exhibited in full development to the north of Swansea. But still farther westward, at Llanelly, an upper series of seams occupy a comparatively narrow area, coursing east and west, where the full thickness of the coal-measures is estimated to amount to no less than 10,000 feet. If, therefore, we include these, where they are worked on the north-east of Llanelly, and extending to the Llwchwr River, we have the following full section:—

Uppermost or Llanelly series, 1,000 feet, with 8 seams, and a total of 18 feet of coal.
Penllergare series, &c., 3,000 feet, with 16 seams above 18 inches, and a total of 50 feet of coal. (Down to the Hughes seam of Swansea.)
Swansea sandstones (Pennant), 2,700 feet, with 15 seams and 28 feet of coal.
Lower series, 400 to 1,400 feet, with 18 seams and 83 feet of coal.

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[*] According to surveys made by Mr. T. Forster Brown, F.G.S., H.M. Deputy Gaveller in Dean Forest.

The local variations, and especially the thinning out eastward of many of the beds, render a general section, such as the above, inapplicable except to a limited part of the area.

On the west of Carmarthen Bay the thickness of the measures is again greatly reduced, and their value is much deteriorated by the violent foldings and convolutions to which they have been subjected, and which may be seen at their maximum in the cliffs of St. Bride's Bay.

The north-eastern part of the field is principally remarkable for its excellent partially bituminous coals. In the neighbourhood of Aberdare the seams acquire in the highest degree those free-burning and yet smokeless properties, which adapt them especially to steam purposes. The run that has consequently been made upon the coals of these valleys, has led to the opening of such numerous, and such vigorously worked collieries, that large tracts of the best seam, the Aberdare four-foot, have already been exhausted. From hence westward the coals of the south outcrop remain bituminous as far as beyond the Llanelly district, whilst those along the northern side of the field change to anthracite, and this latter variety of coal alone is yielded by the seams rising northward in Carmarthenshire, and by all those of Pembrokeshire. Even within a distance of a few hundred yards, the Llanelly beds are seen to be bituminous where they rise to the south, and anthracitic in the opposite side of the trough.

The produce of the western districts has been as follows:—

	1854.	1864.	1878.
	Tons.	Tons.	Tons.
Gloucestershire and Somersetshire	1,492,366	1,950,000	1,840,605
Monmouthshire	8,500,000	4,028,500	4,490,290
South Wales		6,948,000	12,926,225

An examination of the constituent strata, and of the positions of these western coalfields, will lead to the induction that they have formerly been united, and that in Dean Forest we have a link between its larger neighbours, which has been preserved from denudation by its fortunately having been folded into a basin form. The twenty miles which intervene between Coleford and the Welsh hills exhibit only the Old Red sandstone, the base on which coal measures once rested, long since swept away by the wearing action of the sea, when the land has been raised after periods of submergence.

IRELAND.—The coalfields of the sister country form a most interesting study to the geologist, but unfortunately yielding only an average of about 140,000 tons, present to the commercial or technical inquirer features of little present value and of no future prospects. He who has passed long days in exploring the hilly coal country of Carlow, Kilkenny, or Tipperary, —now examining the fossils of the shales, which remind him of those of the lowest coal series of central England, and anon looking down upon the wide plains of carboniferous limestone which form the great bulk of the low country,—cannot but soon arrive at the conviction that Nature probably gave to Ireland with a liberal hand, but has again taken away what she had given. The isolated little coalfields which exist at present are but the remnants of important deposits which have been torn away by denudation; and as they are unmistakably the few lowermost beds of the formation, no discoveries are to be expected from boring. It is, nevertheless, noticeable that the lower portions of the carboniferous strata are developed in great thickness, for the limestone is succeeded by several hundred feet of black shale, as in Derbyshire, and then by some 500 to 700 feet of flagstones, which form a parallel to our millstone grit. The coal measures attaining sometimes a thickness of 1,800 feet, contain but a few seams, mostly very thin, of anthracite, extremely broken, compressed, and uncertain, in county Cork, but in the Tipperary and Castlecomer fields, forming basins of considerable regularity.

In the north of Ireland, coalfields of very small extent occur in Tyrone and Antrim; which, although some of the seams are of bituminous quality, exhibit in the main characters very similar to those of the south. And thus the whole of the deposits of fossil fuel, being but fragments capable of a very limited supply, it is fortunate that the town populations of Ireland can be supplied with such facility from the Clyde, Whitehaven, the Mersey, and the Dee; and that Nature has in some measure made amends for the absence of coal by the gift of peat bogs of unsurpassed extent and quality.

CHAPTER VII.

CONTINENTAL EUROPEAN COALFIELDS.

France.—Although unable fully to supply the demands of a large population and high civilisation, the French coalfields are neither few nor poor in contents. The sum total of the coal production of France is obtained from above fifty different patches of the coal formation, only a few of which need to be cited as of permanent importance. They may be grouped as the coalfields of the north, of the centre, and of the south.

That of the north, occupying a narrow strip of land in the departments du Nord and Pas de Calais, is at the one end continuous with that of Belgium, whilst on the other it gradually diminishes in value as it is followed from Valenciennes and Bethune, towards Hardinghen and Boulogne. Considering how the coal-measures are covered by the chalk, or cretaceous strata, 80 to 150 yards thick, some of them offering very serious obstacles to the sinking of shafts, it is creditable to the sagacity and perseverance of the French engineers and coal owners that they have so ferreted out the character and position of these concealed treasures, as to have brought the production of this field already up to over six millions of tons. The seams are not actually traceable without a gap into Belgium, but are of a similar character,—regular and numerous, yet thin: thus the 12 beds of Aniche give together but 23 feet of coal; 4 beds worked at Douchy, 11 feet 6 inches; 18 at Anzin, 39 feet.

A comparison of these features with those exhibited on the flanks of our Mendip hills, and an observation of the underground course of the sharp trough of French coal strata, deflected as it is from its Belgian direction when it arrives at Douay, inclines us to the speculation that the palæozoic rocks may be continuous from the Severn to the Rhine. The question may possibly be of little practical importance, but is one of great interest as regards the original deposition of the carboniferous series.*

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* Mr. Godwin Austen long since propounded this view on purely geological grounds. Quart. Jour. Geol. Soc., vol. xi.

The coalfields of central France are remarkable for their irregular and small area, and the fragmentary and unequal state in which most of the seams occur. They are commonly based upon some of the primary rocks, granite, gneiss, &c.; and a great part of their constituent mass consists of coarse grits, and, towards the base, of rough conglomerate. The seams attain, here and there, a vast thickness, even up to 40, 60, and 80 feet, but are much broken, and subject to sudden changes. Some of the French geologists are inclined to consider them the result of deposition in lakes, in contradistinction to the fields of the North and of England, where they repose on the obviously marine beds of the mountain limestone.

The most important of them is the district of St. Etienne and Rive de Gier (Loire), occupying a length of about 34 miles, and in which the lower seams occupy an area of 60,000 acres. One of these varies from 30 to 70 feet in thickness. On these follow some hundreds of yards thick of barren sandstones, and then an upper series of 20 seams of from 3 to 16 feet thick, which only cover a surface of about 10,000 acres, and in the midst of which the full thickness of the basin appears to be near 5,000 feet. The active manufacturing industry of this neighbourhood has raised the production to more than three millions of tons.

Another remarkable basin is that of the Saône et Loire, the chief working centres of which are Creusot, Blanzy, Montceau, Montchanin, and Epignac, where the measures contain only ten beds of coal, but at Blanzy two of them run from 30 to 60 feet each; and at Montchanin, as at Creusot, one seam attains locally the extraordinary amount of from 60 to 130 feet in thickness.

Most of these central fields are, unfortunately, mere basins in the older rocks, so that their contents are rigidly defined; yet a few of them—as that of Creusot and Blanzy—offer some prospect of continuation, especially on the south-west, beneath the covering of newer formations.

In the south, the coalfield of Alais, in the departments du Gard and Ardeche, conveniently situate for the supply of the coasts of the Mediterranean, and that of the Aveyron, are both of them noticeable for a yield which has increased much within a few years past, and for having probable reserves beneath the jurassic strata, which on certain sides bound the visible extent of the coal-measures.

In 1863, with a home production of 10½ millions of tons—increased in 1873 to 17,485,000—France consumed half as much again imported from abroad.* Since 1815 the amount raised from French pits has been multiplied *tenfold;* but it is still a problem whether the rapidly increasing demand will ever be met by the production of the country. My own visits to a few pits have impressed on me the conviction that the French coal-seams are usually much more difficult to work economically than our own; and that hence the prices, ruling higher than in more favoured districts, will always render it difficult for the coal-owners to compete on the large scale with those of England, Belgium, or Prussia.

Belgium.—The deepest pits in the world have been opened in that narrow, but actively worked, zone of

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* The imports of coal and coke into France were :—

	Tons (1864).	Tons (1877).
From Belgium	3,500,000	3,872,051
„ Prussia	1,800,000	1,091,388
„ England	1,200,000	2,792,907
	6,500,000	7,756,346

coal-measures which runs from west to east by Mons, Charleroi, and Namur, to Liége. Especially in its western portion, the district of Hainaut, the high angle of inclination of the strata, sharply folded and even zigzagged into a narrow trough, has occasioned the shafts to attain in several cases over 750^m, or 2,460 feet; one shaft, at the Viviers Réunis, near Gilly, even 1,040^m, or 3,411 feet.

The Belgian coalfield, which is in all above 100 miles in length, and generally 4 to 6 miles wide, is subdivided into several basins, among which that of Mons exhibits the fullest development of the formation. No less than 157 seams are known by name, of which 120 are workable, varying from 10 inches to 3 feet. The upper series of 47 seams, not seen elsewhere in the country, are the *Flénu*,—a coal burning with long flame and giving off much gas; the next group of 21 are coking coals; then comes a third, of 29 beds of *charbon de forge;* and last, 20 to 25 beds of *charbon sec* or *maigre*, dry coal, burning with small flame.

The production of the different districts of this field was:—

	Tons (1867).	Tons (1877).
Mons Centre Charleroi } or Hainaut . .	9,595,280	10,259,374
Namur	389,586	371,388
Liege	2,770,956	3,307,761
Total . . .	12,755,822	13,938,523

The northern side of this long synclinal trough inclines much more moderately than the southern; and in the sharp-angled zigzag contortions the same contrast between the two sides may often be seen; an arrangement recalling the phenomena of our Pembrokeshire field. M. Dormoy, a French engineer, has constructed some beautiful maps to illustrate his views, and considers that, in consequence of the swerving direction of a great east and west dislocation, the southern half of the trough is wanting, except in the rich elliptical basin of the Couchant de Mons, where the total thickness of the measures is estimated at 8,000 feet.

A striking example of the zigzag structure of the coal-measures is seen in the accompanying section of the mine *des Six Bonniers*, near Namur.

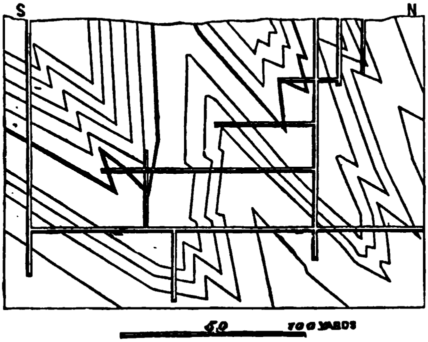

Fig. 10.

The mode of working is generally by a modified kind of long-work, but one requiring a vast quantity of timber, much of which is lost. Within the last twenty years great strides have been made in the improvement of their machinery, and the output at the larger pits is very considerable; whilst the expense of deep sinkings tends, as in the north of England, to increase the area worked from a given pit. The quantity raised per man is much less than the usual English standard, partly in consequence of the thinness and difficult position of the seams. Not long ago all the work-people were, by law, obliged to travel up and down by ladders, but at present many are raised by the cages; and the *fahrkunst*, or, as it has been termed, Warocquière (from M. de Warocquè, who erected an excellent one on his own works at Mariemont), has been applied with great success at several of the larger collieries.

The price of coals in Belgium is very high; 16*s.* to 20*s.* per ton being obtained for large, and 8*s.* to 10*s.* and 15*s.* for mixed and small.* They are divided into the following classes, according to size:—*Houille*, large blocks; *gaillette*, lumps; *gailleteries*, pieces the size of a fist; *gailletins*, or *têtes de moineau*, nuts; and *menu*, smalls, or slack; whilst the name of *gilleteux* is given to mixed sorts.

Prussia.—Almost continuous with the Belgian field, the two highly contorted coal-basins of the Inde, near Eschweiler, and of the Wurm, near Aix-la-Chapelle, have been worked from a very early period; and extending as they do to a great depth, contain large reserves of coal. In the same direction, farther eastward, after crossing the valley of the Rhine, comes the large and rich coalfield of the Ruhr, or of Westphalia; which, although mined near Dortmund as early as 1302, has only within the last quarter of a century risen to a high degree of importance.

That portion of the coalfield which is visible at the surface consists in the main of three parallel synclinals, rich in a vast number of seams, of which the uppermost are a good bituminous coal, the middle series semi-bituminous (*Sinter* or *Ess-Kohlen*), and the lower seams non-bituminous or *Sand-coals.* There are here no less than 117 seams, in 1,203 fathoms of measures, containing an aggregate of 294 feet of coal. Nearly three-fourths of the number are of workable size, and they are now recognised and mapped over the entire district by the aid of three or four *guide-seams* of special character and persistence. Of late years numerous and systematic borings through the chalk strata which overlie the coal-measures on the North have proved the existence of several additional similar folds over a still larger area, so that the prospective value of the field has been more than doubled; and it is estimated that it contains no less than 39,200 millions of tons. But perhaps the most remarkable coalfield of the Continent is that of Saarbrücken, on the south of the Hunsrück range, and on the left bank of the Rhine. In this extensive and isolated tract a greater thickness of measures and of coal exists than anywhere else in Europe. Prussia has the good fortune to possess the lion's share, whilst a small but valuable division, containing the lower seams only, falls within the confines of Rhenish Bavaria (Rhein-pfalz), and the tail end has been proved by borings and sinking to extend within the French frontier.* The coal basin, in

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* The prices mentioned throughout the book refer to the years 1864-6.

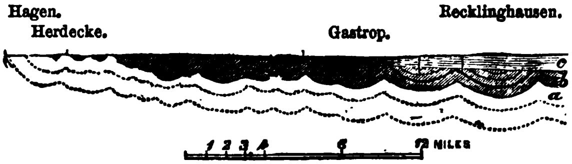

Fig. 11.

a. Lower carboniferous rocks, sterile sandstones.
b. Productive coal measures.
c. Cretaceous strata.

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* Included since the events of 1870 in German territory.

outside measure, is about 60 miles long by 20 wide, and its lower strata attain, in a line from Bettingen to Tholei, the enormous depth of 20,000 feet, whence a great portion of the coal must ever remain practically unattainable.

The Prussian mining officers, under the lead of Nöggerath and Von Dechen, have made most accurate surveys and sections of the measures, from which we find that the total number of seams above 6 inches thick is 164, containing in all, 338 feet of coal, whilst the number at present deemed workable, *i.e.* above 2 feet, is 77, with 240 feet of coal, and they estimate that the quantity of workable coal down to the depth of 342 fathoms, in the three Prussian circles of Saarbrücken, Saarlouis, and Ottweiler, is 2,750 millions of tons, whilst the total amount in the measures for the same limited area would be above ten times that quantity.

In the International Exhibition of 1862, perfect sections of some of these beds of coal engaged attention, and the seams called Callenberg, Schwalbach, Beust, and Blücher, reared up against the walls with their full height of 10, 12, and 14 feet, afforded a fine sample of the products of collieries which now export largely into France. One notable peculiarity in the coals, and in which they differ strangely from those of Westphalia and Belgium, is that the lowest known seams are bituminous or caking coal, and that the higher they range in the series the more *dry* or anthracitic do they become. Of small importance as reserves of fossil fuel, compared with the two last, but yet very suggestive in a geological point of view, are the two isolated protrusions of coal of Ibbenbüren and the Piesberg, near Osnabrück. They consist of true coal-measures, in which from five to seven seams have been proved and worked on a moderate scale. Before quitting Westphalia, it should be added that seams of exceptionally good coal, for the newer formations, occur in the Wealden strata which traverse a part of the kingdom and extend into Hanover and Brunswick. In the districts of Tecklenburg, Minden, Osnabrück, &c., these seams, which run from 10 to 44 inches, are a good deal worked for local purposes, and yield in some places caking, in others anthracitic coal.

Another Prussian coal region, that of Wettin and Löbejün, near Halle, claims attention as forming a link between the north-western fields and those of Saxony. It has long been worked, although figuring to a very small amount in the annual returns.

On crossing the Prussian territories to their south-eastern corner, we arrive at the remote and comparatively unwrought coalfields of Silesia. That of Lower Silesia extends through the circles of Landshut, Waldenburg, and Glatz into Bohemia on the south-west. That of Upper Silesia occupies parts of the circles of Ratibor, Rybnick, Pless, &c., and passes on the one side into Moravia and Austrian Silesia, on the other by Beuthen, towards Krakau. This latter field especially, which was commenced upon only in 1784, is of a value which has not been sufficiently appreciated. Measured at its full thickness from the saddle of Zabrze towards the outcrop, it is stated to contain no less than 333 feet of coal in seams of above 2¼ feet thick; whilst its extent, reaching far beyond the boundary shown in maps, is difficult of limitation, from the fact of the coal-measures passing beneath newer formations. But whilst the total mass of the strata appears to be some 10,000 feet thick, and much of the coal may therefore lie at unattainable depths, it is made out with fair probability that this repository must contain an available quantity, even within a working depth already exceeded elsewhere, of 50,000 million tons of coal!

The structure of this latter coalfield is not yet so thoroughly explored as to give certainty to calculations for the future, but the surveys of men distinguished no less as miners than as geologists, Von Oeynhausen, Von Carnall, and Krug von Nidda, leave little doubt that the district of the head-waters of the Oder may be looked to as a source of supply long after we shall have burned out our last ton of coal from most of the pits of our Western countries.

With the steady advance in production of the Prussian coalfields it may be observed that the most flourishing is that of Westphalia, where the position is eminently favourable to cheap transit, and where consumption has been fostered by the price being lowered considerably below the standard of other Continental producers.

The following table exhibits the quantities raised from the several districts of Prussia during the years 1863 and·1878—

Official Centre.	1863.			1878.		
	Coals.	Brown Coal.	Total.	Coals.	Brown Coal.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Breslau (Silesia)........	4,421,119	188,807	4,609,926	10,381,703	444,254	10,825,957
Halle (Pr. Saxony) ...	52,971	3,645,129	3,698,160	39,233	5,123,661	5,162,894
Dortmund (Westphalia)	6,875,120	1,631	6,876,751	19,208,942	...	19,208,942
Bonn (Saarbrücken)...	2,955,364	190,576	3,145,940	5,568,554	146,787	5,695,267
Clausthal				301,728	126,714	428,441
Grand Total......	14,304,574	4,026,203	18,330,777	35,500,160	5,841,366	41,321,501

The brown-coal or lignite of Prussia, as well as of Nassau and several other North German territories, now commands a great sale as a fuel, well enough suited to many purposes. The shallow basins of tertiary rocks—generally sandstones—which yield it, are scattered in patches over a vast extent of country, but attain special importance on the Lower Rhine, in the Westerwald, in the Wetterau, on the River Elbe, and in the Thuringian district.

The coalfields of SAXONY, although locally important, and interesting as having been geologically well explored by Naumann, Von Cotta, Geinitz and Von Gutbier, are not likely to exercise much influence on European production. That of Zwickau was worked at a very early date, and being found to extend beneath the New Red sandstone, offers a good magazine for future supply. Where best developed on the left bank of the Mulde, it exhibits 9 seams, with 96 feet of coal.

From the careful examination of the coal plants, instituted by the Saxon geologists, it is shown that whilst the undermost seams of Silesia, the *culm* series, may be termed Lycopodiaceous or *Sagenaria* coal, the lower seams of Zwickau are chiefly of *Sigillariæ*, forming *pech-kohle* or pitch-coal; that next above the Sigillaria zone comes the Calamite coal, principally shown in the *Russ-kohle* seam, which attains locally a thickness of 22 feet 6 inches. Above this occurs the Annularia zone, and lastly, including the uppermost seams, the Fern zone.*

The coalfields of Haynichen, and of Potschappel are of far smaller note, but the position of the latter, near Dresden and the silver mines of Freiberg, gives it a special value. On the whole, this little kingdom produced in 1877, of coal and brown-coal together, 3,477,511 tons; the true coal being 2,914,017 tons, raised from 74 pits, by 15,972 workpeople.*

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* The Flora of our coalfields of Gloucestershire and Somersetshire offers, I think, a parallel to the above; but its details need closer examination.

Austria.—The large amount of forest still existing in many parts of the Austrian monarchy has rendered coal a requirement of no serious importance until within the last few years, when the great increase of steam navigation, of railways, and manufactures, has given impetus to the production of every kind of fossil fuel. The true coal formation stretches from Lower Silesia into a limited district of Bohemia, at the base of the Riesengebirge; and that of Upper Silesia forms a tract of considerable importance around Mährisch, or Moravian Ostrau, where it is largely worked by Von Rothschild and others. On the north-west side of Prague the coal-basins of Schlan and Rakonitz, that of Radnitz, and the western one of Pilsen, extending in the aggregate over some 600 square miles, are all being rapidly opened; but no less remarkable are the strikingly thick seams of brown-coal (sometimes from 30 to 50 feet) found in the flat country of Elnbogen, Bilin, Commotau, &c., and largely shipped on the Elbe.

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* The rapid increase of production in Saxony, especially since the year 1830, will be appreciated from the statement of annual raisings at intervals of ten years:—

Year.	Saxon *scheffel*, nearly = 4 cwts.
1790	30,800
1800	62,000
1820	65,000
1830	165,000
1840	780,000
1850	4,200,000
1860	7,874,000
1870	15,082,170

The Austrian States raise in the year above twelve millions of tons, of which over the half is brown-coal, but some of the varieties of the latter are so like good bituminous samples of the older coal that I have seen one of our most experienced Newcastle pit-men entirely at fault in judging of them. A very superior quality occurs at Fünfkirchen in Southern Hungary, and at Steuerdorf and some other localities in the Bannat, where it needs an examination of the fossils in the shales to convince you that they are in the Lias formation. The tertiary brown-coals of Hungary and in the Austrian Alps, especially in Styria and Carinthia, are not only of a very useful character, but occur in seams which in some instances attain the surprising thicknesses of 50, 70, and even 120 feet.

SPAIN.—Although the Mediterranean countries are generally devoid of true coal, exhibiting only here and there deposits of lignite of no great importance, the Spanish peninsula presents a notable exception, boasting a large coal-field of numerous seams superposed on the carboniferous limestone of the Asturias, and two others apparently of great though unexplored value at Belmez and at Villa Nueva, near Cordova. But no great development can be expected whilst the means of communication remain so bad that the habitual transport of the produce of the collieries is effected on donkey-back.*

RUSSIA.—It is no matter of wonder if, in this most extensive of European countries, the abundance of forest, and the scantiness of population, have retarded exploration for coal. But the researches of Sir Roderick Murchison and his associates, Count Keyserling and M. de Verneuil, have proved the existence of a gigantic extension of lower carboniferous rocks, ranging along the flanks of the Ural Mountains, over a length of about a thousand miles. It is only here and there that any coal-seams have been proved to exist; but, although much interrupted, they are distinctly shown to occur on both sides of the great dividing chain.

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* The last twelve years have witnessed a change.

These authors have attached especial importance to the coal-field of the Donetz, between the Don and the Dnieper, near the northern corner of the Sea of Azof; where the middle carboniferous limestones contain a number of workable coal-seams—not remarkable for goodness of quality—over an area of about 11,000 square miles. At the collieries of Lissitchia Balka, 900 feet of measures exhibited several seams, giving an aggregate of 30 feet of coal, and 50 feet of beds of limestone with marine fossils.

Le Play states that he found 225 outcrops with above 400 feet of coal; Prof. Helmersen more recently (1864) asserts the existence of nearly 400 seams;* and as the northern side of the field is covered by the cretaceous rocks, and coal-measures have been already proved beneath them, it appears probable that there is here a vast development of the older coals, of which we have notable examples at home, in Northumberland and in Scotland.

The researches of Auerbach and Trautschold on the coals of central Russia, published in 1860, describe a well-marked coalfield in the Governments of Tula and Kaluga, with an area of above 13,000 square miles.

It appears doubtful whether any seams of the ordinary upper coal have yet been found; but should such be discovered to extend beneath the overlying Permian strata, it seems not improbable that Russia may one day be shown to possess stores of coal, in some degree commensurate with the magnitude of her territorial proportions.

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* *Vide* Quart. Jour. Geol. Soc., vol. xx.

CHAPTER VIII.

COAL OF NORTH AMERICA.

South of the St. Lawrence and the great chain of lakes an astonishing proportion of the surface of the North-American continent is occupied by the carboniferous formation; and if we merely compare the coal-areas of the New World with those of the Old, as indicated in geological maps, we should conclude that the total extent of the deposits of Europe stand, as against those of America, in the humble ratio of 1 to 21. But an important fallacy is involved in these comparisons, inasmuch as the position of the American coal strata, with respect to the under and overlying rocks, is such as to exhibit their entire area (in the midst of which also large tracts are barren), whilst many most valuable portions of the European coalfields are covered by newer formations; and there seems reason to doubt whether in the former there ever occur such great accumulations of coal as distinguish some of the fields of the latter.

In the British colonies, New Brunswick and Nova Scotia are especially noticeable for a great thickness of carboniferous strata, which have been already explored by Prof. Dawson and Mr. R. Brown. The number of seams is comparatively small; but it is interesting to observe that the plants found in or near them belong to the same genera, and often to the same species, as those of the coals of Europe.

The Cumberland coalfield, occupying a tract which rises towards the Cobequid hills, exhibits along the shores of the Bay of Fundy, at the Joggins, an unrivalled natural exposure of strata, which Sir W. Logan has measured to be upwards of 14,000 feet thick. But although 70 seams of coal are included, very few of them, and those only thin, are found of workable dimensions. Near Amherst, the productive division is stated by Dawson to be 2,800 feet thick, with seven seams of from 1½ to 3 feet thick; giving a total amount of not more than 16 feet of actual coal.

A remarkable contrast to this state of things exists in a limited district at Pictou, where, in a much smaller bulk of measures, there occur 5 or 6 good seams, the most noticeable of which is the Pictou main coal, no less than 37½ feet in thickness, inclusive of some bands of shale and ironstone.

In the northern and central parts of Cape Breton, around the town of Sydney, another coalfield, of considerable economic value, forms, according to Mr. Brown, one extremity of a great coal region, the main body of which extends under the sea towards Newfoundland. The same practical author estimates the productive measures as occupying 250 square miles, and as possessing a thickness of 10,000 feet. A fine natural section, on the north-west side of Sydney Harbour, shows a total of 1,860 feet of measures, with 34 seams of coal, but four only among them are workable, each from 4 feet to 6 feet 9 inches. The excellent papers by the two above-named authors, in the Quarterly Journal of the Geological Society of London, contain most valuable contributions to our knowledge of the plants and animals of the coal. The quantity raised and sold in the province, during the year 1865, was 651,256 tons.*

The extensive coal-fields of the UNITED STATES are evidently, from their character and positions, but the huge remnants of a vast coal area, which once extended from the St. Lawrence down to the mouth of the Mississippi, and from the shores of the Atlantic to Kansas and the frontiers of Mexico. Although they may be separated from one another by gaps of many miles in width, the intermediate space is occupied by the same floor of lower rock on which the coal-measures rest; and the productive portion of the strata is preserved in the several basins, by occupying the depressions of the undulated flexures to which the entire mass has been subjected. Most violent on the east, along the line of the Alleghanies, these foldings become more and more gentle westward, so that in the great regions of the Ohio and the Missouri the inclination of the beds is very small, and their unbroken extent proportionally great. Coupled with this fact, moreover, it is found that the character of the coal changes: bituminous and caking in the broad flat areas, it becomes more and more dense when affected by the contortions of the Appalachian chain, until, in the parallel synclinal deposits of Pennsylvania, it becomes a pure anthracite.

Prof. Rogers, in his elaborate "Geology of Pennsylvania," dwells upon another broad feature of general interest. The beds of conglomerate (millstone-grit) and sandstone, which occur in great thickness, and of coarse grain, on the east, gradually thin away and become finer as they approach the west; whilst the slight traces of limestone, associated with the coal-measures in Pennsylvania, become more and more important as they reach the successive western districts, until beds, that in the Potomac basin are only 10 feet, become expanded at Wheeling to 200 feet in thickness. And as the coarseness of grits and conglomerates points to the proximity of the land whence they were derived, whilst the limestones abound in marine organisms, it results that in the coal period deep-sea conditions prevailed in the west; and that the mass of land, from which the sandy constituents of the coal-measures were derived, must have existed where the Atlantic now rolls its billows.

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* 1873, 1,051,467 tons, is reported for 1879 at 788,273 tons.

The coalfields of the United States, estimated by Rogers to occupy an area of 196,850 square miles, are five in number :—

1. *The Appalachian coalfield,* forming a series of producive basins in Pennsylvania, Ohio, Maryland, Virginia, Kentucky, and Tennessee, extends in a N.E. and S.W. direction for 875 miles—an unbroken length, second only to the spread of the lower carboniferous rocks along the western flank of the Ural.

In the southernmost and deepest or the Pottsville trough of anthracite, it appears that about 25 workable seams have been proved, in other parts only 10 or 12; so that, although a maximum thickness of 207 feet of coal has been ascertained, the average would not exceed 70 feet.

Some of the lower seams of the anthracite attain exceptionally the thickness of from 10 to 40 feet, probably in consequence of the local disappearance or attenuation of the shales and grits which elsewhere divide from each other six or seven different seams. At Lehigh Summit mine the great coal-bed is a magnificent seam of 50 feet, containing 30 feet of good coal.*

In the bituminous field of western Pennsylvania, seven to ten workable seams† are found in a thickness of about 2,100 feet of strata, and the same number may be identified in north-west Virginia; whilst, as a proof of gradual attenuation westward, it seems that in the western coal-field of Missouri and Iowa seven or eight workable seams at the utmost are included in about 700 feet of strata.

The upper series, cropping out a little to the north and north-west of Pittsburg, is based upon a remarkable seam of coal, named after that town. Prof. Rogers has traced out, *con amore*, the prodigious extent of "this superb bed," and shows how incompatible with any *drift* theory are its persistency and regularity. With a thickness of 8 feet at Pittsburg, rising to 12 or 14 feet in the south-eastern basins, and dwindling on the Great Kenawha to 5 feet, and at Guyandotte to 3 feet, its superficial measurement amounts to about 14,000 square miles; and if we include some detached basins, which indicate its former extent on the east, it would appear that the Pittsburg seam formerly (before denudation) occupied a surface of no less than 34,000 square miles.

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* To guard against misapprehension, it is well to remember that it appears to be the local practice to name a seam by the thickness of the coal as roughly measured in the driving of a cross cut; and as the beds rise at various angles, the amount thus taken is generally much in excess of the true thickness. Thus Mr. Rogers states that the so-called "39-foot vein" is really 26 feet horizontally measured, and 15 feet measured in an European way, fairly across the seam; and, after all, 8 feet only are of saleable coal.

† Near Pittsburg, above the P. seam of 10 feet, is the Waynesbury coal, 6 feet, and below it 5 seams with about 22 feet of coal.

Another observable feature of the upper series consists in the intercalation of bands of limestone charged with marine fossils, and amounting sometimes, in the aggregate, to 150 feet thick. One bed especially, which overlies the Pittsburg coal, has been remarked to increase from 2 feet in the Cumberland basin to 41 feet at Brownsville, and 54 feet at Wheeling.

The aggregate thickness of coal contained in the measures, generally, of the Appalachian coal-field, is far less than that above given for the anthracite region. Even where the basin is deepest, and the seams are 15 or 16 in number, it scarcely amounts to 40 feet; whence it is inferred by Rogers that, considering the great amount of denudation, we are hardly entitled to assume a higher general average for the whole field than 25 feet.

The coal-trade of Pennsylvania may be said practically to have commenced with the first shipment in 1820, and the following numbers, given in the report of the Philadelphia Board of Trade, show the increase in quantity sent to market at intervals of ten years:—

Year.	Tons.
1820	365
1830	174,374
1840	841,584
1850	3,177,537
1860	8,151,569

For 1875 it is stated to have amounted to 20,973,805.

2. *Illinois and Indiana coalfield.*—This is a somewhat oval tract, lying between a wide anticlinal exposure of Devonian and Silurian rocks on the east, and the saddle of carboniferous limestone of the Upper Mississippi on

the west, having a total area of some 51,000 square miles.

Within this vast district, nearly as extensive as the Appalachian, many local disturbances and undulations affect the strata, and confine the available basins within limits which are not yet thoroughly explored. In western Kentucky, the productive coal-measures are estimated at 3,429 feet thick; the lower series—including a hard sandstone, called the Anvil Rock, at the top—being 1,029 feet, with nine workable seams, and the upper group being 2,400 feet, with eight workable seams and numerous bands of limestone. An aggregate amount of 40 to 50 feet of coal has here been proved; but since all explorers agree that there is a great amount of undulation bringing the older strata to the surface—the flexures running N.W. and S.E., or oppositely to those of the Appalachian range—no satisfactory estimate of the average quantity of coal can yet be obtained.

3. *Iowa, Missouri, and Arkansas.*—In this enormous area, where upwards of 73,000 square miles are stated[*] to be occupied by coal-measures, we cannot but look upon the latter as being of a degraded type; not only the stony strata, but the beds of coal also having greatly dwindled, both in number and thickness. Prof. Swallow, reporting on the geology of Missouri, estimates the total sections of the coal-measures on that river at 650 feet; the upper portion containing thin beds of buff limestone, and no workable coal; whilst the lower group, between Booneville and the mouth of the La Mine, includes six coal seams, two only of which, of 3 feet and 6 feet respectively, are workable.

[*] Rogers, "Geology of Pennsylvania," vol. ii.

Dr. Dale Owen, in reporting on Arkansas, mentions the occurrence of several seams of coal opened upon in different counties for smiths' use; but most of them are only a few inches thick; one alone, the Spadra seam, being 3 feet. They appear to be semi-anthracitic, and to be intercalated among the lower members of the formation ; viz., with the millstone-grit, and close down on the "Archimedes" limestone. Sundry outlying deposits of coal and cannel promise to be of local value; but the contents of the field, as hitherto described, are so utterly disproportionate to the magnificent show which it makes in a geological map, that in a comparison of the coal-measures of different countries, the mere statement of its area is of no value.

4. *Coal-field of Texas.*—This extreme south-western district, estimated at 3,000 square miles in extent, will be looked upon by the geologist as originally an extension of its larger neighbour in Arkansas.

5. *Michigan coal-field.*—A very considerable extent of land, between Lakes Huron and Michigan, and estimated at 12,000 to 15,000 square miles, is occupied by a shallow basin of gently inclined or horizontal coal-measures. The foundation on which they rest appears to be carboniferous limestone; frequently containing, as it does also in British North America, deposits of gypsum. It appears singular that the interior of this coal district is imperfectly known, and that as yet only a few points have been noticed where coal crops out. From these appearances it has been conjectured that but very few beds of workable coal—probably the very bottom of the series—exist here; and a parallel is offered to the bad plight of the Irish coalfields,—robbed of their chief contents by Nature's great planing-tool of denudation.

It will excite no surprise that in a country of which the interior is so scantily peopled, and the timber-land still so abundant, the coal-trade should be but of recent origin, and the quantity of fossil-fuel brought into the market from native mines very inferior to the yield of European countries, in proportion to the extent of the coal-rocks. It was only in 1820 that the first modest instalment of 365 tons of coal was sent from the mines of Pennsylvania; and we have seen that, doubling itself sometimes in five, sometimes in ten years, the amount has increased to above ten millions of tons in 1864. The other coal-producing States lag far behind, as will be inferred from the following table, showing the produce for the year ending June, 1864, and the produce of the principal coal-bearing states for 1875:—

State.	Tons (1864).	Tons (1875).
Rhode Island	3,656	11,176
Pennsylvania	12,698,412	31,641,805
Maryland	787,269	2,380,257
Iowa	?	1,624,000
Western Virginia . . .	398,815	1,117,600
Kentucky	91,036	381,000
Missouri	66,187	762,000
Ohio	1,324,685	4,416,199
Indiana	146,787	812,800
Illinois	925,293	3,566,000
Michigan	16,296	12,192
Minnesota	50,204	?
Kansas	236	279,400
California	44,938	168,758
Washington Territory . .	7,754	90,322

A small amount of lignite is included in these numbers.

The total quantity of anthracite raised in 1875 is given at 20,984,000 tons. The statistics of the other coals are less trustworthy, but it is estimated that they swell the total to 47,433,215 tons for that year.

It is reported,[*] too, that "great looseness seems to exist in the compilation of figures involving large sums, as well as in the returns required to be made by the companies." Whence it is probable that, allowing for local consumption, &c., the amount raised in the States cannot be less than 50 millions of tons.

Years ago the progress of the Pennsylvanian mines would have been much checked but for the duty placed upon the importation of foreign coals, which has been varied from time to time, and is now 1 dollar 25 cents per ton of 28 bushels. The distance from the mines to the chief centres of population, along the sea-board, is from 80 to 120 miles, and the carriage appears to cost nearly as much as the value of the coal at the pit's mouth. The price at New York ranging in general from 22*s.* to 24*s.* per ton, and occasionally (as in 1864) running up much higher, admits an importation into the States of above half a million tons annually.

The great wealth in fossil-fuel of North America does not end with the true coalfields above described. In eastern Virginia, a tract some 26 miles long by 4 to 12 miles wide, contains coal in the lower part of the Jurassic group (with fossils very similar to those of our Whitby beds in Yorkshire), and the main seam is stated to attain the thickness of 30 and even 40 feet of good bituminous coal. The measures form an irregular basin, resting upon granitic rock, and the seams are much disturbed, and subjected to thinning where they are closely superimposed upon their primary bed.[†]

On the Pacific side of the continent, lignites of good quality, and often in seams of from 3 to 10 feet thick, make their appearance at divers localities. They appear to belong to the Cretaceous series; to which age Dr. Hector has satisfactorily referred the lignites of the Saskatchewan River and of Vancouver's Island.

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[*] Reports from Her Majesty's Secretaries of Embassy and Legation, 1866.

[†] This formation is now referred to the Trias.

The geologists and statistical writers of the United States have constructed diagrams and numerical tables, which get handed about from one book to another, and give, as I think, very erroneous ideas of the overwhelming importance of the American coalfields as compared with those of Europe. It may be true enough that a vast area of country is occupied by rocks of the carboniferous period, and a proclivity to big figures may be gratified by calculating the tens of thousands of square miles of extent; but it should be recollected that among the European coal-fields are several in which, as in Westphalia and Silesia, the greater part of the productive ground lies covered by a cloak of newer formations. The total area of coal-measures in the United States is given as 200,000 square miles, whilst that of Russia is set down as 100 miles; and this simple "unit of measure" is then applied as a standard showing the littleness of all the European fields. But if the same method of calculation were applied to Russia that has been acted on in Iowa and Missouri, and we were to take the length and breadth of the tracts over which coal-bearing rocks have been found to exist, and may be deemed continuous, that empire, instead of figuring as a petty unit, would run the States a hard race for mere extent of carboniferous formation.

On passing, then, to what is of more weight—the thickness of workable coal—we are constrained to believe, whilst fully recognising the colossal value of the Appalachian and of the Illinois and Indiana deposits, that the *data* for the estimation of the contents of the others are not yet satisfactory, and that the progress of exploration in such vast tracts will show many an element for subtraction.

CHAPTER IX.

COALFIELDS OF ASIA AND OF THE SOUTHERN HEMISPHERE.

On turning our gaze eastward from Mediterranean Europe to the Levant, we may observe the continuation of similar characters in the rare occurrence of true carboniferous strata, and in the frequent exhibitions of lignites of cretaceous or of tertiary age. The only remarkable instance of the former which we know in Western Asia is the coalfield of Eregli on the south shore of the Black Sea, a district which was urged into some little activity during the Crimean war, but which appears to have so far sunk back again into the old sleepy state of ill-management as not even to supply the limited requirements of Constantinople and the other towns bordering on the Euxine. Every now and then the disclosure of something black cropping out on hill or river side leads to the publication of a paragraph which makes the round of the European newspapers, and tells of the discovery of a new "coal-mine," generally of "inexhaustible extent," and "quality equal to the best Newcastle coal." It turns out to be an instance of the patchy distribution of the lignites, which have seldom been good enough to command serious attention; although in one case, in the Lebanon, considerable workings were carried on for this article during the occupation of Syria by Ibrahim Pasha.

In India, large tracts of land, especially known about the Upper Damoodah and in Burdwan, are occupied by a coal-formation which, besides its extent, is notable for very peculiar geological features. The active missionaries, Messrs. Hislop and Hunter, described to the Geological Society of London, in 1855, the occurrence of plants in the coal-bearing sandstones, some of them of genera which might be taken as common to the coal-measures of Europe, but others, such as Zamites, Tæniopteris, Glossopteris, Vertebraria, and Trizygia, which indicate a Jurassic age. Some of these bear a close resemblance to the contents of our Oolitic coal-beds of North Yorkshire, and to those of Virginia, and the parallel is rendered stronger by the presence of remains of Lepidotus and Æchmodus, Jurassic fish, in the Kotá shales, which appear to belong to the same series as the Nagpur plant-bearing beds.

Messrs. Blanford and others of the geological staff under Professor Oldham, have been working out the relations of these Eastern coalfields; they divide the coal-bearing strata of Bengal into the Barakar, or lower Damoodah, the Ironstone shales, and the Raniganj beds, ascribing them to the upper palæozoic period, and the overlying Panchet group to the Trias.*

Farther to the north-east, the ingenious and closely-packed natives of China and Japan discovered at a very early period the value of the fossil fuel which in both countries exists in large quantity. Writing of the northern part of China, Marco Polo stated, in describing his travels between 1270 and 1290, "Through the whole province of Cathay, certain black stones are dug out of the mountains, which put into the fire, burn like wood, and, being kindled, preserve fire a long time; and if they be kindled in the evening, they keep fire all the night; and many use these stones because that though they have plenty of wood, yet there is such frequent use of stoves and baths, that the wood could not serve."

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* Coal raised in all India for 1868, 547,971 tons, an amount, according to Mr. W. Blanford, F.R.S., not much exceeded ten years later.

There appears to be no doubt that several large and rich fields, producing coals of good quality, exist in China; but we have obtained hitherto only meagre and fragmentary accounts of some of them from travellers unprepared with technical knowledge. On the upper waters of the Yang-tse-kiang coal seams crop out to the surface over a very large area, and are worked on a small scale by levels driven into the hills.

In the prefecture of King-hua, W.S.W. of Ningpo, and near the town of E-u, coal-pits are described by the Rev. R. Cobbold, which have been opened upon seams of a bright non-bituminous coal. The mines are from 300 to 500 feet deep, sunk in lifts of 40 to 50 feet at a time, and having the mineral raised by successive windlasses at the intermediate stages.*

Notwithstanding the facilities of water carriage existing throughout a great part of China, it is manifest that great improvements must take place in the mining operations before these stores of mineral fuel can be made fully available for manufacturing and for the requirements of the steam navigation of the Eastern seas.

A certain amount of prejudice, derived no doubt from negative evidence, disinclines us to believe in the existence of carboniferous formations within the tropics, and the discoveries of coaly substances hitherto made in the warmer regions of the earth have generally tended only to show that beds of lignitic matter were formed even in these latitudes amid some of the later formations, whilst the true carboniferous rocks have not yet been traced within many degrees of the equator. A great local value may attach to these coaly lignites of superior quality when workable in certain situations accessible to steam vessels, as at Labuan and elsewhere in Borneo,* and even on the banks of the Zambesi.

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* Part of the province Schansi, over an area of 1,500 square German miles, is described by Von Richthoven as an anthracite field, with seams 12 to 30 ft., mostly horizontal. V. also Pumpelly's Travels.

On arriving at the southern latitude of Sydney, in Australia, we meet again a great development of the carboniferous system, exercising already a considerable influence on the fortunes of our rapidly growing colonies. Since the systematic description of the coal-bearing beds of this region by Count de Strzelecki, in 1845, numerous observations upon them have been contributed by Mr. Beete Jukes, the Rev. W. B. Clarke, Mr. Selwyn, and Mr. W. Keene, which leave no doubt as to the palæozoic character of the lower part of a great conformable series of strata, although the upper portion presents anomalies reminding us much more of the Indian coalfields than of anything which we possess in Europe.

Mr. Clarke proposes the following general divisions—

1. Wianamatta shales, 700 to 800 ft. thick,	Upper carboniferous, or Permian (Dana), Jurassic (Mc Coy).
2. Hawkesbury Rocks, or Sydney Sandstone, 800 to 1,000 ft. thick,	
3. Upper coal measures, with the coal-seams of Newcastle, &c., 5,000 ft. thick,	
4. Lower carboniferous rocks, 8,000 ft. thick.	

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* See Quart. Jour. Geol. Soc., vol. iv., p. 96, and vol. ix., p. 54.

The presence, along with the coal seams, of such plants as two species of *Glossopteris*, *Cyclopteris angusti-folia*, and certain species of *Sphenopteris* and *Phyllotheca*, gives a parallel to the fossils of strata more recent than the European carboniferous, but there is at present a difficulty in drawing a line of demarcation between the groups No. 3 and No. 4, whilst in the latter both plants and shells of the carboniferous and devonian series are abundant.

Mr. Keene, the Government Examiner of Coalfields, states that he recognises eleven distinct seams, which are more or less worked. Several of these are from 4 to 6 feet thick. The Wallsend seam, worked between Minmi and Newcastle is 9 feet of good coal; that of the Agricultural Company's Bore-hole Colliery is 9 feet; and one which crops out near Stroud, on the same company's lands, is as much as 30 feet, including sundry partings of shale and fire-clay. On the Hunter river, for a distance of fifteen miles up from Newcastle, several considerable collieries are worked, and even thirty miles farther north, at Rix's creek, near Singleton, a good seam has been opened upon. South of Sydney, about sixty miles, at Bellambi and Wollongong, shipments are made of the coal obtained from workings on the outcrops of seams of very regular persistence in thickness.

The products of the Australian collieries are various in character, smith's, household, and gas-coal being obtained from different pits, and a large amount of steam coal of very serviceable quality being regularly supplied to sea-going vessels. Several beds of bituminous shale and cannel, which occur chiefly in the division No. 3, have recently attracted much attention as sources of rock oil. Imitating the mother country not only in the names of its seams and mining localities, New South Wales has opened out a considerable foreign trade, and shipments of coal have long been made to China, India, and even to the ports of California.*

It is not our object in this chapter to do more than invite attention to a few among the coal-bearing formations of parts of the world distant from Europe, which appear to promise future importance. We need not refer, except in passing, to those minor deposits of lignite or of true coal which undoubtedly may be developed and acquire a local value, although unable to weigh much in the coal trade of the world. Tasmania and New Zealand come under this category, and some of the lignites of the latter country stand high for quality.

Turning farther westward, we find that coal-beds exist in the Falkland Islands, and that South America promises great results—of but little value at present, whilst her population is sparse and her forest lands of enormous extent. Very interesting, however, is the coalfield of Santa Fè de Bogota, in New Granada, the fossils of which prove it to be of cretaceous age. Mr. David Forbes has pointed out the existence of true carboniferous rocks near the mountain lake of Titicaca, situated no less than 12,600 feet above the sea; and within the last few years successive notifications have been made of important areas of true coal in various parts of the flourishing empire of Brazil.

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* The coal raised in N. S. Wales in 1876 was 1,319,918 tons, of which more than half was exported.

CHAPTER X.

SEARCH FOR COAL; BORING; AND SINKING OF SHAFTS.

A VALUABLE amount of light may be thrown upon the character of a coal district by surface researches, unaccompanied by the breaking of the ground. Quarries, roads, protruding rocks, sea-cliffs, ploughed fields, and water-courses, will all yield to an experienced eye their quantum of information. Even when, as in parts of Lancashire, the general surface is occupied by a thick cover of clay, gravel, &c. (the *drift*), good facts may be gleaned in the channels and banks of the brooks which have cut their way down to the harder rock. Now and then a very complete view of the raised edges of a whole series of strata may be seen; as in the cliffy shores of the Bay of Fundy, Nova Scotia, and of Cape Breton; whence we have sections, measured by Sir William Logan and Mr. R. Brown, embracing thousands of feet of strata. In the county of Carlow, Ireland, in South Wales, and in the North of England, there are frequent opportunities of thus obtaining a measurable profile of some of the lower coal-measures.

In this kind of search we must learn to avoid being deceived by vain resemblances. Especially dangerous is it to trust to mere outward likeness in the shales or "metals" to those of the coal series: such may belong to the Silurian, to the Lias, or to other formations. If true carboniferous shales, we ought to be able to find in them some of the fossils proper to the period, before pronouncing on them. Still more irrelevant is it to form conclusions on the presence of coal-measures because the surface is covered with a cold clay, or because you have limestone on one side of your field of action, or because ironstones have been found about the place. Each of these circumstances *may be* true of a coalfield, but is not necessarily so: each may also be true of many other formations, and would require corroboration by other characters. The presence of a spring of water depositing ochreous oxide of iron is often noticeable near the out-crop of a coal-seam, but the mineralogist will recollect that, since this appearance is derived simply from the decomposition of iron pyrites, it may occur in many other classes of rock in which that common mineral has been accumulated. Not even the underclay, with its matted, carbonised roots, is sufficient evidence of the nearness of a bed of coal, for such a material has sometimes been deposited, and either the conditions for the abundant growth of the coal-plants have not supervened, or the coal may have been formed, and subsequently been removed by natural denudatory action.

In these cases, a pick and shovel may sometimes lend useful aid; but more commonly it becomes advisable to resort to "boring," either for the actual testing of a particular spot, or for filling up the gaps between portions which may be tolerably well determined at the surface.

This subject has been already treated in one of the Rudimentary Treatises by Mr. Swindell, and we shall therefore touch on it but briefly

The ordinary mode of boring through the alternating rocks overlaying or forming a coalfield is by means of a steeled chisel, or *bit*, of various form, screwed to rods of the best bar-iron, about an inch thick, screw-jointed at intervals of from 6 to 18 feet. At the spot selected for the bore-hole, it is usual either to erect a wooden-staging, or to sink a preliminary pit to a few feet or yards in depth, so that a greater length of rods may be drawn at once, and part of the tedious delay of screwing and unscrewing may be avoided. To aid in this object, too, a tall triangle, derrick, or shear-legs, with sheave, should be erected; within which the rods may be drawn and lowered by the agency of a windlass. In order to lift the rods and cutter a few inches for each stroke or blow, either a spring-pole may be used, fastened down at the but-end, and with the rods suspended at the thin extremity; or a windlass, round which a rope coming from the rods is passed with two or three turns, whilst a man holds the "slack," and when the cutter is raised to a sufficient height by the men at the windlass, slips the rope to allow the rod to fall. Meanwhile a rotatory motion is given to the rods at each stroke by the master borer and his assistant, holding a cross-bar which clutches the upper rods a little above the surface. The chisel thus at each blow cuts the ground in a fresh position, and when this action has been continued long enough, the rods are withdrawn, by unscrewing length after length, and the "sludger," an iron tube of 6 feet long, with a valve in the bottom, is lowered by a rope, and being dropped heavily several times to the bottom of the hole, soon gets filled with *debris*, which being then brought to the top are carefully examined, whilst the rods are again lowered, to go on with the pounding action.

In order to reduce the time and expense of this mode of boring, the Chinese system of boring by a rope instead of rigid rods, has been a good deal employed of late years; but it is open to the objection of sometimes making the hole untrue, and more often of ending in the catastrophe of a broken rope, and of the heavy iron cylindrical cutting-tool remaining at the bottom of the bore-hole.

Exploring bore-holes are generally from 3 to 5 inches diameter, and may be guarded against many of the accidents to which they are liable, by being lined with pipes of sheet-iron, added on from above as the hole increases in depth.

When larger diameters are to be employed, and greater depths than 300 or 400 feet attained, the serious difficulties which supervene are met by various contrivances, such as the hollow rods first successfully used by Œynhausen, wooden rods with iron connections, the free-falling cutter first devised by Kind, &c.; but as these relate chiefly to the boring of Artesian wells for water or for brine, we need but mention them here.

We may, however, cite as, perhaps, the most remarkable borehole yet accomplished, one which has not long since been completed by Herr Kind, for exploring purposes in the coalfield of Creusot, in France, to the depth of 920 metres, or 3,017 feet English.

Steam-power has for these purposes been largely employed of late years. Messrs. Mather and Platt have made remarkable borings by their ingenious cutter worked with a flat wire rope; and several patents have been taken out in England and Scotland for different means of applying this more economical power, whilst Messrs. Kind, Dégousée, and Mulot have severally availed themselves of it in their great works in Germany, France, and Belgium.

At some mines a set of boring-rods is specially kept for exploratory work, and for occasional operations to assist the working of the mines; whilst in many of our districts the work is performed under contract, by borers who devote themselves to this particular task.

The tariff for boring at Newcastle was, in 1854,

for the first five fathoms	7*s.* 6*d.*	per fathom.
,, second ,,	15*s.* 0*d.*	,,
,, third ,,	£1 2*s.* 6*d.*	,,

and so on; irrespective of charges for carriage, fixing apparatus, and boring through rocks of unusual hardness, as *whin*, &c. For deeper bore-holes, *i.e.*, from 1,000 to 2,000 feet, it is difficult to give an approximate idea of the expense; but thousands of pounds are soon involved, and cases might be quoted of such operations in this country where the cost has been at the end no less than £9 and even £12 per foot!

A patent was taken out in 1844 by Beart, and a similar plan practised by Fauvelle in France, for hastening the work by employing a tube as the boring-rod. Down this tube a stream of water was made to flow, in sufficient volume to carry off and bring up, round the circumference of the bore-hole, the *débris* made by the cutting-tool.

The abrading power of diamonds set in a steel ring and at the end of a tube rapidly rotated, as suggested by M. Leschot about 1866, has been largely adopted for bore-holes of from 500 to 2,000 feet deep.

A great advantage which boring possesses over the ordinary sinking of a shaft is that the operation can be carried on without the necessity of pumping out the water. In order to combine this source of economy with the mode of gaining personal access to the coal, shafts from 3 to 15 feet diameter have in Westphalia been sunk by gigantic boring apparatus; successfully, so far as related to the total cost, and forming a process applicable with great advantage if only a suitable lining or tubbing can be inserted, and a water-tight junction effected below the points of influx of water. (See p. 119.)

The shafts by which all collieries are opened and worked, except the few which in hilly districts have the advantage of free drainage, are generally circular in England, though many elliptical and a few rectangular ones may be seen in South Wales, and the latter form is common on the Continent. In Belgium a polygon of 10, 12, or even 16 sides is a frequent form, and is adopted, like our circular ones, for the better resistance, by aid of the special kind of lining employed, to the pressure exerted upon it from the rock around.

A very few only can now be seen of the little old pits, like draw-wells, of 4½ feet in diameter; and whilst for ordinary purposes they are now commonly 8 or 10 feet diameter in the clear, they attain when intended for an important upcast, or for a large get of coal, to as much as 16 or even 20 feet diameter.*

The actual sinking, when in ordinary coal-measures, is effected by the heavy pick, called a *hack*, by hammers and wedges, and by blasting with powder; whilst the broken ground is raised to the surface at first by a common windlass or jack-roll; then, as the work gets deeper, by a *gin* or horse-whim, and afterwards by a steam-engine, often a temporary one only, to be replaced, when the pit is down, by the regular winding-engine.

But when the measures are covered by other and more absorbent strata, saturated with water, the *winning* of a colliery becomes a most serious undertaking, tasking the energies of the best men, and sometimes collapsing after a ruinous outlay.

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* Elliptical pits have been sunk in South Wales and at Chatelinaux, in Belgium, as much as 20 and 22 feet in length.

Examples of these difficulties are afforded by surface beds of sand and gravel, by the well-known red sand under the magnesian limestone, through which so many of the North-country pits have been sunk, and by the *terrains morts* encountered by the colliers of Mons and Valenciennes.

As long as the coal seams are accessible at small depths, managers are liberal in the use of shafts; indeed there are districts where the great number of old shallow pits are a positive nuisance to the modern workers. But as expenses increase with depth, it becomes an object to work a larger area from one establishment of pits, and for this purpose it is worth while to improve ventilation and the underground carriage, so that shafts at frequent intervals shall not be needed. Even when flying along in a railway train you may remark the difference; how in parts of Staffordshire you will see the ground riddled with crowds of pits, whilst in Durham and Northumberland a single "plant" of pits and engines will work the ground for a mile or two on each side.

The cost in extreme cases being some £60,000 for a pit of near upon 300 fathoms in depth, and being stated once or twice to have amounted to near £100,000, there is a great temptation to make this *one* suffice; and by means of *brattices* or divisions (of wood, or brick, or stone), wonderfully good mining has been done in the Northern coalfield with a single shaft. But since the sad catastrophe at Hartley, which resulted from a concatenation of omissions and misfortunes, an Act of Parliament requires that where there is no second outlet another shaft shall within a limited period be sunk. Many of the larger works, however, are able to apply a special shaft to the ventilation as an upcast, whilst at others coal will be drawn, and at one of them the pumps worked.

When the measures through which the pit is sunk consist of stony rock, they are often allowed to stand open, but when shales preponderate, and in all cases where much traffic is carried on, the pit would become a dangerous thoroughfare, and has to be walled with brick or stone, to which in some cases, as against the influx of water, wood or cast iron may be preferred.

In fragile ground the commencement is to secure the shaft by temporary timber. Curbs or *cribs*, rings formed of segments of wood, are prepared, to fit the dimensions of the shaft; and, having their joints in the direction of the radii of the circle, will when 4, 5, or 6 inches square, resist a heavy pressure from the sides. They are supported at intervals generally of about 3 feet, by a few upright props, and are, as it were, hung together by thin planks, termed *stringing deals*, which are nailed against them, whilst the whole structure may be temporarily suspended, if need be, by attaching it to a couple of stout balks laid across the top of the shaft. Behind the cribs a *backing* is formed by driving down planks of some 6 feet long, close together in bad ground, or at small intervals in favourable rock. When a firm foundation of stone or bind has been reached, a bed is prepared with hacks or chisels to receive a broader curb of either wood or cast iron, and on this a wall of brick-work is built up to the surface, or above it when tip-room is required. The pit is then recommenced, of smaller diameter at first, afterwards opened to its former dimensions, and at a suitable place a fresh length of walling is begun, and carried upwards till by careful adjustment it is made to coincide with the upper length and to join up to its curb. In some few cases, where soft material has to be passed through, the walling has been built at the surface, held together with tie-rods or clamping bars, and gradually sunk downwards by cautiously removing the ground from beneath the curbs upon which it is constructed. But where actual quicksand occupies the surface, various other contrivances have to be employed. The method of *piling* is to drive down iron-shod 3-inch battens of 12 or 14 feet in length, supported by curbs, and forming a circle as much larger than the ultimate size of the shaft as to leave room for successive inner circles of piles down to the depth at which solid ground is expected to be found. The sand is of course excavated in proportion as it is practicable to drive down the piles; and at length, when a firm foundation is reached, a broad

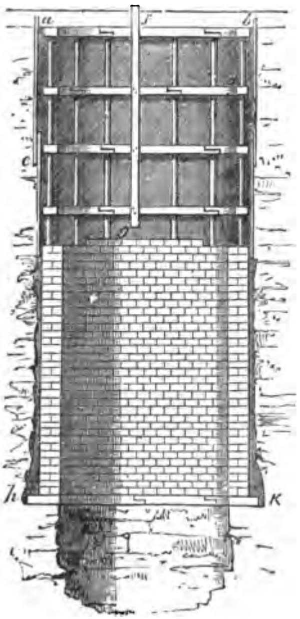

Fig. 12.
Scale, 1 inch to 10 feet.
a b, c d. Curbs of the timbering.
a c, b d. Punch props.
a e. Backing planks, shown in section, but otherwise omitted for clearness.
f g. Stringing deal.
h k. Curb for the walling.

curb is laid, and the walling built up in the midst, whilst the space around it is carefully filled up and packed closely.

To obviate the expense and delays of this system iron cylinders have been in some cases sunk by pressure; but this again, from the difficulty of keeping them vertical, and (if they be intended as the permanent lining of the shaft) from the obstacles to making a water-tight joint with the solid ground at the bottom, is a very troublesome process. In order to accomplish the latter object, M. Triger, in the year 1845, introduced in France the ingenious idea of keeping out the water by forcing down compressed air. He formed, by means of a flooring in the tube, a lower air-tight compartment, in which he found it feasible to work under a pressure of as much as 3½ atmospheres, obtained by air-pumps driven by a steam engine, and by this means succeeded in establishing his water-tight joint at depths of 60 and even 82 feet. For the more convenient working of this method a second chamber was formed above his lower working one, which had a trap-door communicating with the shaft above, and another opening into the chamber below; and one of these doors being always closed whilst the other was opened, the excavated material could be drawn up without any serious loss of the compressed air. A stand-pipe, passing from the surface down into the bottom of the working, afforded a ready means for the water to rise in a constant stream. Triger's method has been applied with success in several shafts in the valley of the Loire, and more recently at some difficult sinkings in Belgium and Westphalia.

One of the most important benefits conferred on coal mining has been the introduction of *tubbing* of shafts (*cuvelage*, Fr.) largely practised in the North of England, and on a somewhat different method in Belgium, Northern France, and Westphalia. Whenever large springs or feeders of water occur in the sinking of the pit, and a series of water-tight measures intervenes between the watery beds above and the seam of coal beneath, it is possible by this means to keep out the whole or nearly all of the water, and thus to relieve the mine of a constant and sometimes ruinous water-charge.

Towards the close of the last century several of the shafts near Newcastle were thus fitted with *plank-tubbing.* At a small distance below the watery strata, a *bed* was carefully cut and dressed to receive a wedging-curb of oak, between the segments of which thin deals were placed edge-ways; the joints were then wedged with wedges of seasoned fir introduced by means of a flat chisel, and the space between the curb and the stone at the back was similarly driven full of wedges. Lighter rings of wood, the *spiking curbs,* were then placed at intervals of 18 inches to 3 feet, according to the pressure, and to these were fixed by iron spikes planks of 2½ or 3 inches thick, bevelled to suit the sweep of the shaft, and the whole structure was thus carried up to a point above the watery strata, and there capped by another well-wedged curb. Thus the water was prevented from entering the pit, and a pressure of as much as 100 lbs. to the square inch could be resisted.

The corrosion of the spikes, and the consequent serious leakages, have caused the abandonment of this first method.

Soon afterwards the solid *wood tubbing* was tried, which is now largely practised in the polygonal pits of the Belgian and French collieries. A wedging curb, *trousse picotée*, is, as before, placed on a carefully smoothed bed, and sometimes superposed on a narrower one called the *trousse colletée;* thin slit deals are placed between all the joints, moss or oakum is packed in at the back, and by wedging, as long as a chisel can be made to enter, all the joints are made tight, and the space at the back crammed full with thousands of wedges—at first of a broad flat shape, and afterwards narrow pointed ones. The tubbing itself consists of blocks of good oak or elm, with the joints well planed to fit, and lined with sheeting deal for farther wedging. In the polygonal pits the vertical joints are made to coincide, the horizontal ones are irregular. As before described, the length of tubbing is carried up past the watery ground, and capped by another wedging curb, or joined to an upper length of similar work. A tubbing of this kind has the advantage of resisting the action of corrosive water, and when well executed, withstands a pressure of two or three hundred pounds to the inch. At Carling, in the Department* of the Moselle, a pit has lately been sunk by M. Pougnet, to work seams at 230 and 280 metres depth, and it has been tubbed in the manner above described, for a length of no less than 160 metres, or 524 English feet.

The forcing down of cast iron cylinders has in many cases been successful; but when the diameter is large, and the tubbing needed at some depth in the shaft, they have been cast in segments, having flanges towards the inside of the pit by which they were bolted together. This variety has now become almost obsolete since the introduction of the modern method, but is nevertheless capable of doing good service, especially in going down through alluvial matter at the surface. My friend, the late Mr. Fletcher, M.P., F.R.S., by this means carried a shaft successfully through sixty feet of coarse gravel and boulders, full of water, in the valley of the Derwent, between Workington and Cockermouth. This shaft is 12 feet diameter in the clear; the lower ring of 18 inches high was sharp-edged below, and above this only the vertical joints were bolted, the horizontal ones left free to a little play. The exterior of this tubbing is of course flush, to facilitate its passage downwards, and the joints lined with sheeting deal to make them tight.

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* This is within the district recently ceded to Prussia.

The great facility of dealing with cast iron, or *metal* in any desired pattern, has led to the special advancement of this variety of tubbing in England. The commencement is very similar to what has already been described. One, two, or three wedging curbs, according to the pressure expected, in segments of cast iron, are laid and wedged with the greatest care, since perfect tightness here is of the utmost importance. Upon the upper one the plates or segments of tubbing are built up, sheathing of pitch pine, ⅜ or ½ inch thick, being inserted between *all* the contact surfaces, and the vertical joints broken, as in stone work. The plates are from ¾ to 1¼ inches thick, and between 3 feet and 12 inches in height, according to the amount of pressure to which they will be exposed. They are smooth towards the inside of the shaft, but strengthened on the outside by flanges and cross-ribs, supported by brackets. Before being placed, they should be tested for soundness by being smartly struck all over with a moderately heavy hammer. Every segment has a hole in the middle, through which the water may escape until the whole structure is prepared. The vertical joints are meantime wedged, but the horizontal ones, for fear of lifting the plates, wait until a sufficient height of segments has been built up, and is surmounted by another wedging curb. Then, beginning at the bottom, oaken plugs are driven into the centre holes as the water rises behind the plates, and the wedging of the joints is completed. The air or gas must be allowed to escape freely above the water, and caution

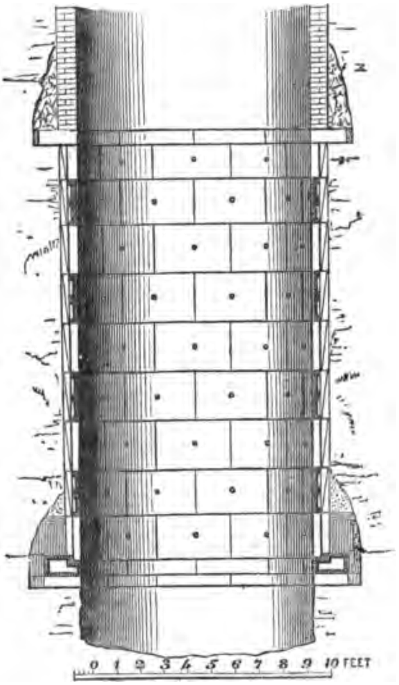

Fig. 13. Cast-iron tubbing resting on two wedging curbs, the upper one hollow cast iron, the lower one of wood.

therefore is exercised in not plugging too rapidly. Should any aeriform fluid thus be imprisoned it will be apt to burst a plate or blow out the sheathing; and in order to relieve the pressure, a pipe is sometimes fixed from the upper ring of plates to the next length of tubbing above, and again from that to a higher part of the pit.

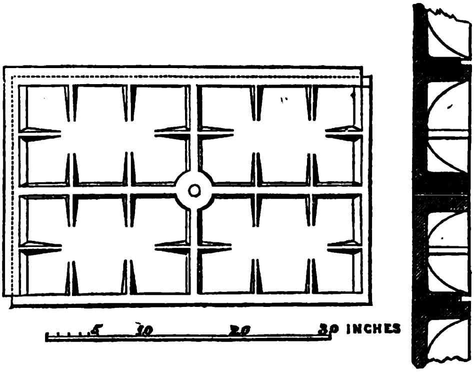

Fig. 14. Cast-iron tubbing plate, elevation and cross section.

One of the most remarkable instances of tubbing is that of the Shireoaks Colliery, recently opened by the late Duke of Newcastle. The pits are 515 yards deep to the "top hard" seam, 12 feet diameter, and the tubbing in 11 lengths, extends for a total depth of 170 yards, and weighs about 600 tons in each pit. My friend, Mr. C. Tylden Wright, under whose supervision it was completed, informs me that the pressure at the bottom was about 196 lbs. per square inch, and that the cost of the lower and stronger part was as follows, per yard:—

	£	s.
126 cwts. of cast iron at *7s.*	44	2
Fixing ditto	3	0
Wedging, about	3	0
Laying rings (about 10 yards apart) . .	10	0
	£60	2

In order to give a vent to air and gas, taps and pipes are applied, communicating from behind the tubbing to the surface, through which a large volume of water is now discharged; and by the final completion of the work in 1858, heavy feeders of water, which during the sinking yielded as much as 500 gallons or 2¼ tons of water per minute in the two pits, have been thoroughly excluded.

Cast iron is so subject to destruction by the corroding action of the water, and of the smoke and gases from the ventilating furnaces, that many schemes have been tried for its preservation; a close lining of brick answers well, but makes it difficult to get at and wedge up a leak or replace a faulty plate; a coating of paint or tar, and a lining with wood (3-inch brick-work at Shireoak) are more or less efficacious.

M. Chaudron, a Belgian, has succeeded in tubbing pits by a method which is proved in watery ground to offer great economy. The shaft is *bored* by Kind's apparatus, and the cast-iron tubbing lowered when the boring is done. The bottom ring of the tubbing has a sliding case, in which is placed a quantity of moss or oakum, which when the whole length of the tubbing comes to rest on the water-tight bed cut for it by the borer (under water) gets so packed as to form a tight joint. The water is then pumped out, and the pit is ready for wedging and completion. At the colliery of Péronnes, where the watery strata extended from 141 to 344 feet deep, the pit was tubbed at one-fourth the usual cost.*

In Westphalia much attention has been given to tubbing with stone set in hydraulic cement, but although applicable in some cases, this method is comparatively clumsy when a heavy pressure has to be met, and the cement is liable to destruction in furnace shafts. The first outlay for a substantial tubbing, whatever be the material, is no doubt very serious, but the great advantages to be gained when it can be suitably applied are such as to make it desirable to extend the practice more generally. It is not only a benefit to the mine in relieving it of a heavy and constant charge, and or the interruptions and accidents inseparable from the use of large pumping apparatus, but it is an advantage to all the dwellers round, and may thus interest the general public, as retaining the waters in their natural channels, and thus obviating that destruction of springs, which is often charged upon the miner as a heinous offence by other members of the community.

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* A full account of new examples of the successful application of this method was given by the author, in the Trans. North. Inst. 1871.

CHAPTER XI.

DRIVING OF LEVELS AND CUTTING THE COAL.

THE preparatory work of a colliery is far from being completed when the shaft has reached the bottom of the seam. It would be ruin, especially in deep workings, to attempt at once to extract coal in any quantity, for the weakening of the ground by its removal would not only tend to bring in or destroy the pit, but would crush the roads which should remain open as thoroughfares for the working of the distant parts of the "royalty" or field of operations.

In the first place, then, a large mass of coal should be left unwrought around the pit as a *shaft-pillar*, having only the narrow drifts cut through it, which are to be employed as roads and as channels for air and water. Next, the levels or drifts for these purposes are to be driven out in the directions required by the lie or position of the strata. Where the beds have a definite dip in one direction, the working pits are usually placed as far towards the deep as it is convenient to go, so that, underground, the coal may be brought down hill to the pit-bottom. But as the workings advance, it may after a time be convenient, instead of sinking fresh pits farther to the deep, to sink the existing pits deeper, and drive out cross-cuts, or to work down-hill and bring the coal upwards by engine power.

The annexed figure represents in section the valuable upper seams of the Flintshire coalfield, where they dip

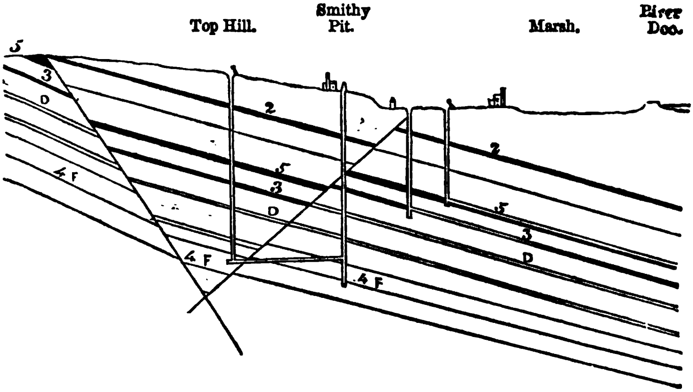

Fig. 15. Section of coal seams at Bagillt—160 yards to the inch.
2, 5, and 3 are the two, five, and three-yard coals respectively.
D and 4 F are the Durbog and four-foot seams.

beneath the estuary of the Dee. The pits at Top Hill have cross-cuts driven through the measures ; the pits nearer to the marshes have down-hill drifts carried in the inclination of the seams.

Should the strata lie in a *trough*, the pits may advantageously be placed in its middle line, so as to command the coal on both sides.

In those few districts where coal still remains to be got by "free drainage," the workings will be started much the same as from the pit-bottom, the levels being driven at once into the hill-side; but the arrangement is usually a defective one for quantity, as not allowing so readily of extension in each direction.

One of the most serious questions to be solved by the coal-viewer in the very outset is the system by which he means to work his mineral; and in order to form a judgment upon this head, it is important that he should not only be acquainted with the various modes in use elsewhere, but should have acquired a knowledge of the peculiarities of the seams in his own district. The first step must be nearly the same in all cases, although it may be so much the simpler as the colliery is shallower, smaller, and not required to stand open for so many years. This step is the opening forward of the levels, drifts, or way-gates, which are the pioneers of the excavations, and must precede, at least to some extent, the removal of coal on any large scale. They are, in fact, generally characterised as narrow, or *dead* work, in contradistinction to the wider working places which follow, and which alone are expected to be remunerative.

Is the proprietary well provided with capital, the extent of area not very great, and the ground firm, the levels may be driven to the boundary of the royalty, and the coal worked back towards the shaft, leaving the dangerous spaces from which the coal is extracted (the *waste* or *goaf*) behind, entirely done with. But if the opposite conditions hold good, coal must be got as soon as the levels have advanced sufficiently far beyond the shaft-pillar.

If the water is to be mechanically raised from the workings, the pit will have to be sunk to some little depth beneath the seam, for a *sump*, in which the drainage may collect; and it is well, in addition, to open out, on the deep of the intended roads, sufficient excavation to serve as a pound, or *standage*, for water, where it may accumulate for a few days in case of breakage of machinery.

A level cannot be driven singly, unless divided into two parts for the in-going and out-coming currents of air; and hence it is usual to prefer to drive two parallel ways, with a rib of from 6 to 10 yards thickness between them, cut through at intervals as required for the ventilation. The lower of these is the drain, or water-gate; the upper, the main road, rolley-way, or way-gate; whilst in extensive collieries a third is usually added, for more efficient ventilating arrangements.

In coal seams of moderate thickness, these leading drifts will be carried between the floor and roof of the seam, and of such a width as is most consistent with their security, commonly from 5 to 10 feet. If the seam be thicker than 6 or 8 feet, it is usual to leave a part of it overhead as roof; if, on the other hand, it be too low for convenience as a horse-road, either some of the roof must be ripped down, or a sufficient depth dug up from the thill or floor. Few of the roads, however, comparatively speaking, will stand long exposed to the pressure from all sides, and to the nearer to the marshes have down-nill drifts carried in the inclination of the seams.

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oxidising action of the air, without being artificially secured. The most usual method of effecting this important end is with timber placed in sets of three, at intervals of 3 or 4 feet. Two of them, commonly larch poles, or sometimes oak, 4 to 8 or 10 inches thick, are placed as uprights, legs, or stanchions against the sides, and the third laid crosswise upon the heads of the others as a cap or head-piece. When the roof is apt to crack off, it is additionally protected by planks laid upon the cap-pieces from one set to the other. Or better still, and in some cases absolutely necessary, is the arching of the main roads with brick or stone, now and then—when the floor is very soft—resting on an invert flat arch below. Especially near the pit bottom, where more room than usual is wanted for two trains of waggons, and wherever a pass-by is required, it is needful either to construct a good wide arching, or to have the wooden caps so long, that they should receive the support of an additional prop in the middle.

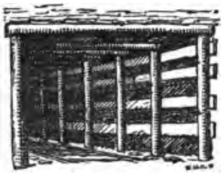
Fig. 16.

It is obvious, although sometimes neglected, that in order to obtain the full advantage from the timber, the direction of the main pressure should be duly considered, and that no unnecessary cuts should be made in the pieces which may weaken their full resistance; also that the caps should be so fitted as not to act like wedges in splitting the uprights as soon as the weight presses; and again, that in inclined seams, the props should be placed at right angles to the floor and roof, so as to prevent their being forced out of position by the weight from above.

Instances might be cited where, as soon as the main roads have to be maintained near extensive workings, it is found to be the better course to remove all the coal, and to trust to pack-walls, built up of *débris* to sustain the roof, rather than to leave a rib of coal.

Although commonly called *levels*, and carried theoretically in a horizontal line, at right angles to the main dip of the bed, these drifts cannot be carried perfectly level, or the water would not flow back towards the mouth or the pit-bottom. Add to which a certain moderate amount of inclination is needed in order to facilitate the bringing out of the loaded trains or waggons. A rise of 1 in 130 appears to give the *maximum* of effect to horse-power in drawing the full waggons down, and the empty ones back, but 1 in 200 is often adopted, especially where it is an object to gain the greatest possible area of coal from a given winning. In certain districts, as in Dean Forest, a colliery may be limited on the deep side, by a level to be driven from a certain point, in which case the utmost endeavour will be applied to drive it as nearly horizontal as practicable. The men occupied in driving will often be found to swerve upwards with the floor of their drift, and constant attention is therefore needed to keep it in its true direction; and when intended for a traffic road, to make it as straight and regular as possible. In former days all the little rolls and inequalities of the beds were closely followed; but at present, when the cheap conveyance of large quantities is a more prominent object, they are, when it is feasible, neglected, and the levels cut boldly through coal or stone, as the case may be. When *troubles* or dislocations occur, their magnitude must determine how far this regularity may be carried out, or whether the level will have to be swerved from its direction in order to catch, at the nearest distance, the coal on the farther side of the line of fault.

In certain modes of working, the removal of the coal will begin at once from the rise side of these main levels, but in others, upper pairs of levels will be driven parallel to the first, and connected with them by rise drifts, or cross-headings at certain intervals. In other modes again, the chief working places will be started from pairs of up-hill drifts (*bord-gates*) carried up the rise of seam.

The expense of this narrow work is to a great extent got rid of, when, as in certain varieties of *long-work*, to be presently described, the levels themselves can be included in a broad face of excavation, which is simply pushed forward in advance of the remainder of the colliery.

We may here glance at the cutting or hewing of the coal, which in the levels has to be effected by much the same means as in the larger workings, although the greater amount of labour which in the former must be expended on a given quantity of coal, and the smaller size into which it is cut and broken, renders it necessary in general to pay the men by so much per yard on their progress, instead of by the ton or tram.

The *pick* (pike, slitter, or mandril) is the special tool of the collier, much varied in different districts, even for cutting coal; and of different weight and strength in the same pit, according as it is intended for under-cutting (horizontally), for shearing, or cutting vertically, or for working in shale or stone. The handle (shaft, or hilt) is from 27 to 33 inches long, and the double-pointed head from 18 to 20 inches; sometimes straight or nearly so as in central England, and in some varieties of the Belgian *rivelaine*, frequently a little curved, and sometimes in the North mucn "anchored." The points are steeled and sharpened four-square, with a very narrow cutting edge.*

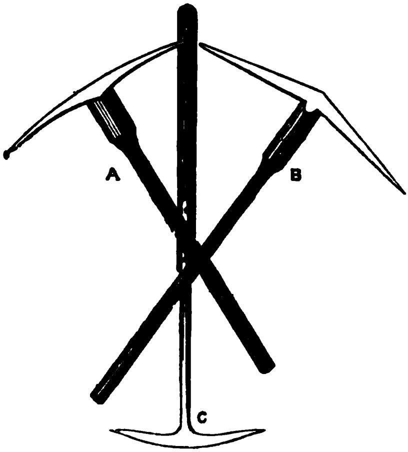

Fig. 17. Scale, ¾-inch to 1 foot.
A. North Staffordshire holing pick.
B. Anchored pick, Durham.
C. Rivelaine, Belgium.

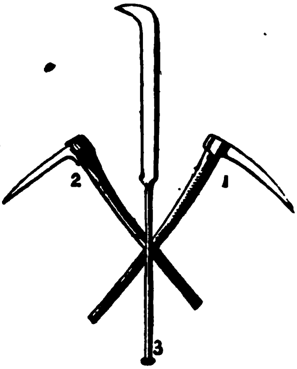

Fig. 17*a*. Scale ½ inch to 1 foot.
1. Coal-pick, Landshipping, Pembroke
2. Do. Westphalia.
3. Do. (*Haveresse*) Liége.

In breaking down or getting the coal, the first operation is to *bench*, *kirve*, or *hole* it along the bottom of the seam, or in other words, to cut a groove to the depth of two or three feet either in the lowest part of the coal, or in the clay that underlies it. If the clay be tough and hard, it often follows that great waste is caused by holing in the coal, for as the groove advances in depth, it must also be cut higher at its commencement, and the whole of the material is chipped so small as to be useless. Some coals are so strong as to require no support during this operation; others, which are tender, or divided by frequent planes of cleat, backs, &c., require to be propped or *spragged*, especially when, in very deep holing, the hewer has to place himself almost beneath the seam which he is detaching. For thus holing at the bottom of the seam, the collier lies on his side, and in this apparently constrained attitude swings the pick almost horizontally, and delivers a number of smart and well-pointed blows before he proceeds to remove the *débris*. In certain seams there may be an advantage in holing in the middle, or even at the top, according as partings of soft shale or friable coal may occur; and in one and the same colliery you may sometimes see two or three methods of holing in practice.

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* Coal picks with single point are rarely to be seen in these islands, in Pembrokeshire they have been used for the anthracite; but on the Continent they are common.

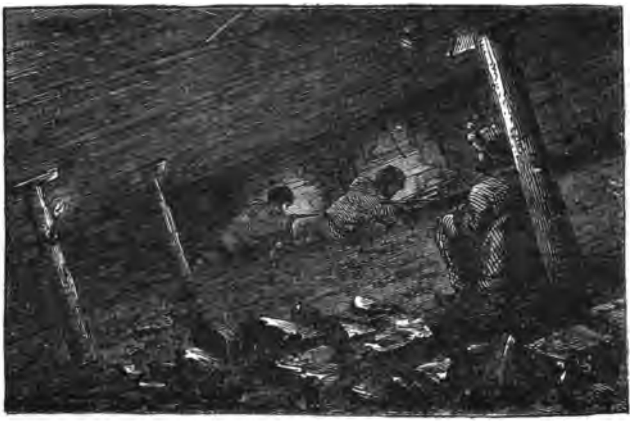

Fig. 18. Colliers holing Coleford high-delf seam, Forest of Dean.

When the coal to be cut away is a short block, as in the driving of levels, it will generally need *shearing* or vertical cutting to free it at the sides, and even in wider workings this operation is sometimes required; then at length the final breaking down or "falling" of the seam thus partially freed is completed by applying taper wedges at some few feet apart, and driving them with heavy hammers; or in the case of a more resisting material, by blasting with gunpowder. The operation of boring a hole and firing the shot for this latter purpose is very rapid and easy as compared with the blasting in hard ground. A *drill*, with broad and sharp bit, is quickly driven forward by hand in the soft and brittle coal; the hole is usually dry; plenty of safe tamping is at hand; risk there is none in using an iron needle (except of course in stone); and danger is only to be apprehended where fire-damp is apt to be present, and where the anomaly exists of using safety lamps and yet firing charges of powder.

This state of things has in fact caused frequent accidents, which can only be guarded against either by allowing the practice under the careful supervision of officers, or by forbidding it and giving the men a so much better price for their work as will be needed to make up for the smaller amount they can get by wedging as compared with blasting.*

Some seams there are which will not bear this systematic mode of work, where the coal will not stand to be holed, and must be picked down in irregular pieces. In collieries in the South of France I have seen this operate as a drawback to cheap "getting" and to obtaining a due proportion of large coal. But a magnificent example to the contrary is the pure "spiry" four-foot seam of Aberdare, where, at Mr. Nixon's Navigation Pit, a pick seems to be hardly needed; one smith suffices to sharpen for 300 men, and the coal in the face comes down so readily that a man has only to show it the point of a bar, and in a few minutes has spread before him masses enough to fill a tram!

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* It is probable that much manual labour will be spared by the introduction of *coal-cutters*, worked by steam, compressed air, or water. Several ingenious machines have already been put to practical work, among which we may cite those of Messrs. Firth and Donnisthorpe, of Messrs. Levick, and the hydraulic slotting machine of Carrett, Marshall, and Co.; but it would be premature to express an opinion on their general applicability.

CHAPTER XII.

POST-AND-STALL, AND LONG WORK.

Is the general form in which the colliery is to be laid out determined on, the position of the shafts, main levels, and direction of the working faces settled by local conditions, we have next to solve the question of the best mode of the working away (*exploitation*) of the coal.

The most simple and natural method would appear to be, to open ranges of working-places, each as wide as the nature of the floor and roof will admit of with safety, and each divided from its neighbour by masses of coal broad enough to sustain the pressure from above. This is in fact the rudimentary idea of the system of *post-and-stall*, or *bord-and-pillar*, (*stoop-and-room* of Scotland). In fullest opposition to this method is that of removing the whole breadth of coal over a long continuous face, supporting the roof at the immediate "face" by temporary props, and allowing the superincumbent strata to break down bodily at a few feet distance behind the workmen—*long-wall* or *long-work.* Other modifications there are, which partake more or less of the character of one or other of the above two systems, and which are in vogue in special districts.

The post-and-stall work is most largely practised in the Northern collieries; but in one form or another is met with in most coal districts, and is sometimes called for by particular conditions, such as thickness of seam, tenderness of coal, or position of workings beneath sea, rivers, or other surface which must not be disturbed.

In the earlier stages of coal mining, it is apt to be the case that the working-spaces (*stalls* or *bords*) driven across the grain or *cleat* of the coal are made as wide as possible, and that the pillars between them are left as thin as is required for immediate security. Thus, towards the outcrop of the Durham coalfields extensive areas have in former days been worked where the bords were from 3 to 5 yards in width, and the pillars between them 1 to 3 or 4 yards. As the bords advanced it was necessary to communicate between them for ventilation, and cross-drifts, called *headways*, were carried about 2 yards wide, *in the direction of* the cleat, or *on the ends*, and at 28 or 30 yards apart. Where the pillars were only 3 or 4 feet thick, it is obvious that they would soon be so crushed as to be utterly useless, and thus a third or a fourth part of the coal would at once be wasted by this means alone. When the pillars came to be laid out of 4, 8, or 12 yards *to the wall*, or in breadth, and it was found towards the end of last century, that they might be *robbed*, or have a great deal of coal taken from them after the first opening of the bords, it became a matter of moment to adopt the proportions which would be most favourable to the full utilisation of the seam. Two great evils have to be avoided, evils on so large a scale that tens of thousands of acres have been rendered useless to the community by the neglect of proper dimensions. One of these is the *thrust*, which when pillars are too slight, and when the floor is hard, cracks the pillars, forces off large slabs of coal, and at last crushes the whole into slack. The second is the *creep*, a disorder more uncertain and insidious in its approach, and which in spite of all attempted remedies, will sometimes destroy a valuable colliery. It arises when the thill or underclay is soft, and the proportion of pillars to bords such that after a time a downward movement takes place; the pillars then force the clay to rise upward in the bords, the road-ways are injured and have to be constantly repaired, the air-ways are partially choked, and the pillars crack. The mischief has perhaps taken its rise only at some unusually weak place, against a *trouble;* but as it spreads from bord to bord, and infects an entire district, the floor bursts asunder, the roof, unequally supported, breaks down, the workings are closely filled with rubbish, and there remain the isolated *crept pillars*, only accessible by fresh and dangerous workings, and generally so crushed as to be nearly worthless.

The experience of the Newcastle miners has led them, especially in their deeper pits, to increase more and more the dimensions of their pillars, employing them no longer as mere supports, but taking out in the preliminary stage of working in the *whole coal*, only from ¼th to ⅙th of the coal, and leaving the pillars for subsequent entire removal, when operations are commenced *in the broken.* Hence, in the deep collieries the pillars are left of 24 or 30 yards long, by 16, 18, or 24 yards wide, and even 40 yards by 40.

In the earlier days of pillar working it was usual to open out in bords and headways-drifts extensive areas, amounting often to many hundreds of acres, and to begin the thinning or removal of the pillars only after they had stood for a long time. Sundry disadvantages arise from this course—the deterioration

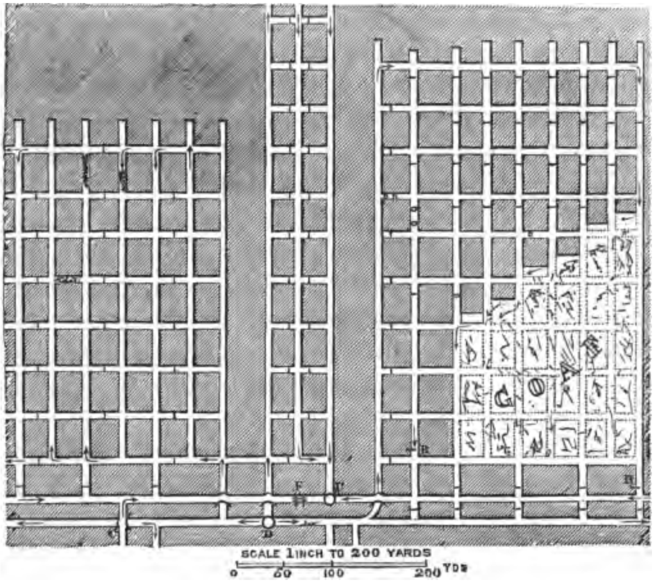

Fig. 19. Post-and-stall work.

D. Downcast shaft.
U. Upcast shaft.
F. Furnace for ventilation.
R. Regulator for ventilation.
C. Crossings for ditto.
D D. Doors for ditto.

The arrows indicate the direction of the air currents.

of the exposed surfaces, the difficulty of ventilation, and the tendency of creep or of the results of explosion to spread through the entire colliery. Mr. Buddle introduced a great improvement when he laid out the workings in *panels* or compartments of moderate acreage, divided from one another by ribs of coal 40, 50, or 60 yards wide; and when he followed up this division of the colliery by making pillar working follow very closely after the opening of the bords in the whole coal.

This arrangement is shown in the plan Fig. 19, where the unwrought coal is left black, and the *goaf* or portion from which the pillars have been removed, and into which the roof has fallen, is lightly shaded.

The actual getting of the pillars is managed in various forms—by driving a bord through its midst, by taking off slices parallel to its longer face, or by paring it off in a succession of steps, each farther pillar being a grade more reduced in bulk. Some of these operations may thus be assimilated a good deal to the *long-wall* method; and need, for the due protection of the men, that the faces of work be protected by rows of props, or by pack-walls so placed as to regulate the fall of the roof.

The Lancashire post-and-stall system is somewhat different, partly in consequence of a generally steep inclination, and partly from the softness of the floor. The seams, like those of the Tyne and Wear, are generally between 3 and 6 feet in thickness; but the working places cannot be carried so wide as in the former district. The working drifts, or *bays*, like the above mentioned bords, having to be directed at right angles to the cleat or divisional planes, it happens that with the varying undulations of the coal-measures, the direction of cleat remaining constant, they may have to be arranged very differently in starting from the main roads or water-level drifts. Thus if the level course happen to be parallel with the cleat, the bays will be opened up the rise, and again joined with one another by drifts carried on the end, generally ten yards apart. If the direction of the level course be at right angles to the cleat, it will be thus also that the bays must be opened, and they will be connected with the main roads by pairs of drifts (up-brows) carried up the rise of the seam; or sometimes if working to the dip of the main road, by down-brows, whence the coal has to be pulled up by engine power.

The pillars are thus left ten yards on the rise, by 20, 30, or 40 yards the other way, and are intended to be *robbed* as soon as a sufficient tract has been opened. This last operation, as in the Northern fields, in contact with the *goaf*, and exposed not only to the successive falls of the roof but to the invasion of fire-damp loosed from the disturbed measures, needs every caution in its practice, and makes it often necessary to admit safety-lamps alone, whilst the other parts of the same colliery may be securely worked with candles.

There are still many coal-mines in which the stalls or *wickets* and the cross-headings or *thirls* are driven as wide as they will stand, say 5 yards, and pillars of only 2, 3, or 4 yards square are left; or where again, the stalls are driven of this full width, and long pillars of a few feet thick left standing between them. In either case a considerable waste of coal must occur, and the irregular openings left as goaf are fraught with danger when fire-damp is present. The method most usual in South Wales is of this latter kind; cross-headings are driven out from the main level at such an angle of obliquity as to be convenient for horse-roads, whilst from the latter the working stalls are opened, narrow at the entrance (to protect the roads), and wider inside. The pillars between them are left so narrow that they are sure to be much crushed; and though some portions of them may be robbed, a large amount is wasted. The ventilation becomes irregular and difficult, and many accidents arise.

A last variety remains to be mentioned, viz., the "square work," employed for the getting of the magnificent seam, varying from 25 to 36 feet thick, called the Dudley Thick or 10-yard coal. The shafts are sunk to the bottom of the seam, and a main way, the *gate-road*, is carried forward in its lower coals, ventilated by means of a separate *air-head* or drift of very small dimensions opened in the coal also, at a few feet on one side of, or above the gate-road.

From this latter the main workings, called *sides of work*, are opened in the form of a square or parallelogram, 50 yards in the side, or more, and shut off by a rib of coal 7 or 8 yards thick, at the least, from all

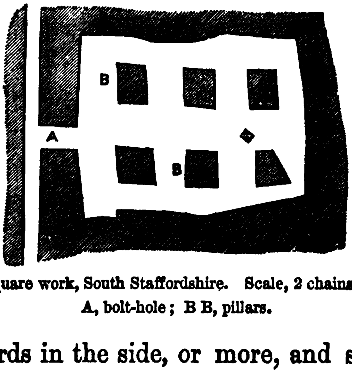

Fig. 20. Square work, South Staffordshire. Scale, 2 chains to the inch. A, bolt-hole; B B, pillars.

other workings, except at the entrance, a narrow *bolt-hole.* Driving out in the lower coals, and gradually rising to the higher ones, the colliers open stalls of 5 to 8 or 10 yards wide, forward and across, so as to leave square pillars, generally 9 or 10 yards in the side, and whenever the unsoundness of coal or roof appears to require it, sparing additional supports of coal in *men-of-war* 3 or 4 yards square.

The men get at the upper divisions of the seam by standing on the slack and coal already cut, or on light scaffolding. No ordinary timbering can be used to support so high a roof, nor can the eye in these vast and murky chambers easily detect where special danger threatens overhead; but the sense of hearing comes valuably into play, and a sharp ear often catches the preliminary cracking which indicates the approach of a fall. Nevertheless, the work is the most dangerous in which the collier can be engaged; and no mode of getting this coal with a less serious destruction of life by "falls" has been devised, except that of working it in two "lifts," by the long-wall method, which, in despite of much opposition, appears, at a few works, to have stood successfully the result of many years' practice.

The pillars in the "square work" are often in conclusion thinned to a smaller size, and when at length the roof begins to break in, the side of work is abandoned, a dam put into the bolt-hole, and thus the air is excluded from the heaps of waste small coal, and the crush prevented by the ribs from extending to other parts of the pit.

It scarcely needs to be added, that although after this first working, operations may be set on foot for getting *ribs* and *pillars*, much of the coal is so crushed or "frenzied" as to be of little use. The waste of some thousands of tons of coal per acre, and the great sacrifice of human life in the process, lead one to contemplate with no pride or satisfaction our mid-English working of the finest seam of coal in Europe.*

Some of the coal seams of central France, although more broken up than the last, are much thicker, and have led to many varieties of working, in order to find out the safest and best. In the Department of the Saône et Loire, I learnt on a recent visit that every other mode has given place to the working by *remblais, i.e.*, taking a horizontal slice of 2 metres in height across the seam, and filling up the space with stone and earth brought down from the surface. At Montceau, near Blanzy, I found the seam to be no less than 78 feet thick, inclined at about 20 degrees. The works are carried forward horizontally from floor to roof, 6 feet 6 inches high, alternating with "middlings" of coal of the same height; and within a few months of the working and stowage of one horizon, fresh openings are made in the range below, and the remblais or stowage is found to be so closely packed as to form a very good roof for driving under—assuming the use of plenty of timber. The *plan* of the working is in pillars of 10 metres wide, which are sliced off as in long-wall working.

The LONG-WALL method may be applied, either by driving out roads in the solid coal to the extremities, and then working back, leaving nothing but *goaf* or *gob* behind, or, by commencing at once near the shaft, to work away the mineral, maintaining means of access to its fresh face by roads, artificially supported, through the waste. Beyond this, great differences occur, according as to whether the faces of work need to be straight, following the lines of cleat, or are divided into "stalls," or may be set off in several directions at once. The working faces are for the most part so arranged as to advance *against* the planes of cleat; but there are certain tender coals in which it will be found that *when the pit is deep*, they are upon this system

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* The risk to which the men are subject in this district from falls of roof and coal may be inferred from the inspector's figures.

Deaths from "falls" in South Staffordshire and East Worcestershire:—1856, 88; 1857, 81; 1858, 97; 1859, 92; 1860, 75; 1861, 78; 1862, 79; 1863, 55.

Later years have shown a marked improvement.

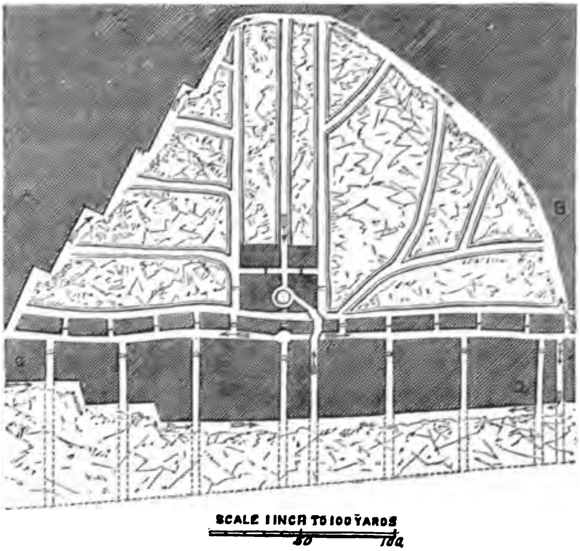

Fig. 21. Long-wall workings.

The portion A represents advancing *stalls*, or *tooth-work*, taking the *face* of the coal; the side B works in the *end* of the coal, whilst the part C D is carried in a straight line irrespective of the cleat. The double edge of the gob-roads represents the pack-walls.

much broken up by the pressure, and that a far better proportion of round coal will be obtained by working *on the end*, *i.e.*, in the direction of such cleat. The most regularly laid out varieties of long-wall are those of Shropshire, Leicestershire, and Derbyshire; but others, more or less modified to suit local requirements, may be seen in Lancashire, Somersetshire, Dean Forest, South Wales, Scotland, Belgium, and Saxony.

Without exceeding the limits of a book like the present, it would be impossible to dwell upon the details of the various kinds of long-work, but the diagram, Fig. 21, may show some of the chief features of several plans of arrangement diverging from one pair of pits.

In some instances it will be seen that a great length of face may be opened in a single line, as much indeed as 100 to 400 yards; in others 30, 40, or 50 yards of straight face form a stall, and one such is followed up closely by another. In many instances again, the face forms on the large scale a curvilinear working, which may be adopted when the coal is not so divided by *cleat* or *backs* as to cut more freely one way than another.

Let us now turn our attention to the "face" or front of the working, which, as it is but a few feet or yards away from the waste, where the roof has "come down," requires to be carefully protected. The usual way is to plant a double row of props (sometimes three rows are needed) arranged alternately, and at right angles to the roof and floor. Each prop takes a good bearing on the roof, by carrying a piece of wood, the *lid* or *tymp*, 12 or 15 inches long, which first receives the pressure, and is soon squeezed or broken. Cast iron has been occasionally employed for the purpose, but the props are usually of larch, or, in low seams, of oak, and whilst with unsound roofs they have to be set thickly, in the common way they may be many feet apart. Where the heaviest roof-pressure is expected, *nogs* or *chocks* are employed instead of single props; these are pieces of timber 2½ to 3 feet long, built up, two and two, cross-wise, thus giving a broad base and summit, and the advantage of being easily knocked asunder for removal. Suppose the coal now holed to a sufficient depth all along the face, the pressure of the overlying mass will tend to force it down, and in some cases actually saves the collier the labour of falling the coal by itself performing that office in the course of a few hours. Otherwise, by wedging, or blasting, the coal is brought down, then broken up and removed. And now, all slack, unsaleable coal and rubbish being thrown behind the men into the gob or waste, the back row of props is pulled out, and they are set up again in front of the fresh face of coal, when the whole operation starts for the succeeding day *de novo.* Meanwhile the removal of the coal from the face towards the shaft is a care of the first magnitude. If the roof be excellent, the coal strong, and the out-put important, iron rails

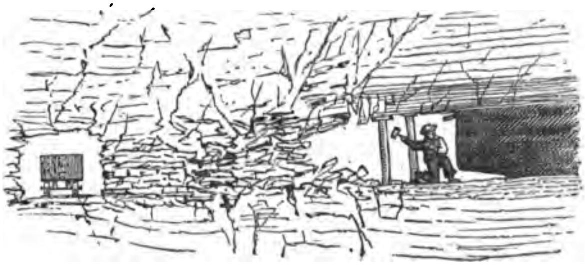

Fig. 22. Cross section of long-wall face.

(to be moved from day to day) may be laid along the face, on which the trams or tubs will be cheaply conveyed. But when, as most frequently happens, this advantage cannot be had, the coal has to be dragged or *putted* in sledges along the uneven floor in front of the face to the nearest outlet, and it hence becomes necessary to have roads opening on the face at frequent intervals. If we are working back from the extremities, no more need be said than that the roads, as the work advances, are constantly being shortened, and that the expense of their maintenance is thus diminishing; but if we follow the usual method, the *gob-roads,* as they are called, are daily increased in length, and the charges of keeping them in order become a very heavy item. There is then one evil to be balanced against another; on the one hand the expense of numerous gob-roads, on the other the cost of *putting* the coal a great distance to get to the road. A working stall is for this reason commonly from 24 to 50 yards in breadth, so that the broken mineral need not be conveyed more than 12 to 25 yards to be placed on a good road. If the coal be a thin seam (and as little as 11 inches of coal is thus worked in the Radstock district) the roads must, for efficient conveyance, be cut higher, for which purpose either the floor or roof must have a foot or two taken off, whilst the material or *débris* so broken, will help, like "partings," "dirt-bands," and other rubbish from the seam, to fill up the waste or gob, and assist in letting the roof down gently. Such stone, and what breaks from the roof, is often built up in *packs,* or masses of dry rubble walling; and the roads which pass through the gob have thus to be protected by a pack-wall of some feet thick on either side. Management will do a great deal in regulating this apparently dangerous work, for each kind of roof needs to be studied, that it may be brought down in the safest manner. Some kinds will break short, so that you are insecure a single foot behind the back props—nay, in bad cases will smash props and everything up to the face of the coal; others will bend gently down to the refuse or gobbin, and press the whole firmly together; whilst certain rock roofs will hold up for a long distance unpropped, but are apt to break suddenly with a crash which will blow out all the lights far and near, and if there be fire-damp about, may force it dangerously into the roadways.

The gob-roads meanwhile stand the pressure variously; in some the floor rises, and has to be frequently repaired. To this end, men occupied in *roading* work during the night, whilst the pit is otherwise clear. Or the pack walls gradually squeeze down, and the roof requires to be hacked or shot away to give height, and, after a time, the road will be found to be almost entirely cut in the roof-stone. In certain districts it is attempted to protect the roads by leaving a thin rib of unworked coal on each side; but an unequal resistance is in this way offered, which generally entails a greater expense in the long run.

In some of the Welsh and Forest of Dean collieries an economical method is adopted for working by the long-wall, and forming their main-level roads by the same process. Instead of driving a pair of narrow levels as usual, a bold face of work, 20 to 50 yards in breadth, is pushed bodily forward, the requisite roads are *packed* on both sides, and additionally fortified, when needed, by timber, whilst the space behind them, partly filled with refuse, forms a portion of the general waste or gob.

The great advantages of the "long-work" method are simplicity of plan (and consequently of ventilation) and the entire removal of all the coal; added to which, under most circumstances, are greater safety to the men, and a larger proportion of *round* coal in comparison to *small* or *slack*,—a matter which, considering the prices, is of vital importance in the selection of the mode of working. It has been mostly practised where the seams are thin, or where they contain a band of refuse; but neither condition is indispensable: for, on the one hand, coals of 6, 8, or 9 feet thick are at the present moment worked advantageously in this manner; and on the other, we have seen bind, or stone *débris*, carried from one seam to another, or even taken down from the surface to assist in the packing where it was needful. Nor is it necessary that the roof be good, although the expense will be very different according to its fragility; but if the operations be carried on with sufficient smartness to push the working-place daily under a fresh or "green" roof, it may be managed upon this system, even when composed of mere fire-clay with slippery joints. Only a few years have passed since the long-wall was much decried, except in a few localities; but its manifest economy is gradually introducing it elsewhere; and even in some of the deepest Durham collieries it is successfully applied to the working off of their gigantic pillars; whilst in a few of the pits near Dudley it has been employed for removing bodily first the upper and afterwards the lower half of the 10-yard coal, with greatly increased yield of coal and security to life.

In Yorkshire and in some of the North-Welsh collieries, methods have for a long time been practised which unite some of the characters of the pillar system with a certain amount of long-wall.

From the main levels, which are protected by sufficiently massive ribs of coal, bord-gates (generally in pairs) are driven up the rise of the seam in advance of the main workings, and between them *banks* are opened in the form of bords of 20, 30, or 40 yards wide, and, like the bord-gates, worked across the grain of the coal. The roof of course falls behind the men, so that the face has to be protected by a double row of props, and sometimes by leaving small pillars, which are mostly lost. If the ground is bad, pack-walls are also built here and there, to prevent the falls being too sudden; and by similar walls an air-way is carried along part of the side of the bank, so that the ventilating current shall pass along its upper end. But the roof here does not settle in the same uninterrupted manner as in the regular long-wall work; and the establishment of a number of separate goafs in proximity to, and generally below, the places where the colliers are working, renders outbursts of gas extremely dangerous, and has led to the fearful explosions of the Ardsley Oaks, Darley Main, Warren Vale, and Lundhill collieries.

Indeed, so fraught with danger has been this plan of working—even where other requirements had been duly attended to—that some of the collieries of the Yorkshire district have been recently changed into long-wall workings, and apparently with very advantageous results. And under this head we must remember that, since the distribution and quantity of the ventilating performing useful service underground, were largely employed for the transit of coal at the surface, and it was thus that the miners of the North laid the foundation of the modern railway system, which in the last half century has been brought to its present perfection and world-wide usefulness chiefly by the agency of the same class of men. A railway was constructed in 1789, at Loughborough, by Mr. William Jessop, of Derbyshire, with cast-iron edge rails, intended for a flange on the waggon-wheel; and rails of wrought-iron were at length invented in 1820, by Mr. Birkenshaw, and were rolled at Bedlington, near Newcastle.

My esteemed friend, the late Mr. Nicholas Wood, after a long series of experiments made in conjunction with his associate Mr. George Stephenson, published in 1825 a practical work on "The Establishment and Economy of Railways;" and more recently, in 1855, prepared a most valuable treatise on the conveyance of coals underground in coal mines. To this excellent paper, published in the Transactions of the Northern Institute of Mining Engineers, and based on a vast number of examples and experiments, I must refer the reader for further details on this important subject.

The conditions under which the roadways of a mine are placed, their frequent sinuosity and unevenness, the confined space, and the tendency to disturbance both in the roof and floor, render it impossible to compete in economy with railways laid upon the surface. Moreover, certain requirements, in connection with the raising of the mineral in the shafts, have to be kept in view, and necessitate the use of particular kinds of waggon.

Until within a few years past the northern method was to fill the coals, at or near the face, into a large basket (*corve*) of wicker, having an iron bow, and to drag it on a small carriage, or *tram*, generally by a pony, to the crane-place on the main road, where it was lifted, and placed with several others, on a *rolley*, or larger waggon, on which they were then drawn by a horse to the pit bottom, whence they were raised to the surface, whilst the rolley returned with a load of empty corves.

In the central districts the principle remains even now much the same; instead of the corve a *skip*, having a strong bow of wrought-iron for raising it, is placed on a *trolley*, and loaded with coal, by having several broad iron rings placed loosely over it, within which the lumps are stacked up. It is then wheeled away to the shaft, where it is hooked on to the rope or chain by the bow.

In Somersetshire and in Belgium the method generally in use, until very lately, was to convey the coal in waggons to the shaft, where it was capsized into a great iron bucket, holding about a ton, called the *hudge* (*cuffat*, Belg.), which was then drawn up the shaft, and had to be again unloaded at the bank.

It is unnecessary to follow up the variations in these modes, which are applied to the conveyance of the mineral in different coalfields, but we may usefully glance at the steps which, within the last quarter of a century, have totally revolutionised the methods of all our larger British collieries. When the cast metal tram-plates came into vogue, the old broad wheels of the waggons, or rolleys, were superseded by cast wheels, fined off very sharply at the periphery, in order to diminish the friction; and these are still extensively retained at many works of importance, partly from want of appreciation of the newer methods, partly from the desire to fully utilise the materials of an old-established plant.

As the scale of operations increased, the expenses attaching to the use of corves were found to be so serious as to lead to the resumption of small wooden waggons or *tubs*, with wheels of 8 to 15 inches diameter, which are run from the face of the coal to the pit bottom, without the delay and cost of lifting a smaller on to a larger carriage, and without involving the other great objection of unloading and loading, to which some of the methods are open. It appears, at first sight, undesirable to have to raise in the shaft the weight of the rolling apparatus, the wheels, axles, coupling-chains, &c.; but the preponderating advantage of running the same waggons throughout, and the facility of raising them at high velocity through the pit by the application of cages and guides, have been universally established as a successful innovation, in the Northern and many of the larger works of other coal districts.

When the seam is thick and roof good, the tubs may, as above stated, be taken close up to the face of work; but the more the actual present workings are hampered by lowness and want of room, the higher will be the expenses of *putting*, &c., in addition to carriage along the main ways. This work used to be carried on almost exclusively by boys, but in the Northern collieries great numbers of Shetland and other ponies, of 3½ to 4 feet high, driven by younger boys, are employed for bringing the coal from the face to the horse-roads or the engine-planes. Where very thin seams are worked, as in the Somerset coalfield, the cost of "carting," as it is called, becomes very onerous. The height of the coals, averaging between 13 and 28 inches, scarcely leaves room in the lower places to go on all fours, and renders the work so laborious that, although the distances are not very great, it costs from 8*d.* to 1*s.* 9*d.* on the ton to cart the coal from the face through the twin-ways and branch roads to the main level.

The movement of the carriages on the roads is retarded by three kinds of resistance: 1st, the friction of the periphery of the wheels on the plates or rails; 2nd, the attrition on the axles; and 3rd, the rubbing, by oscillation of the waggon, of the face of the wheels against the flange of the tram-plate, or the flange of the wheel against the upright rail. The first is diminished either by narrowing the edge of the wheels, or by running broad wheels on edge rails, and by increasing the diameter of the wheels; the second, by careful make, using steel axles and efficient lubrication; the third, by making the wheels fast to the axle, instead of having them loose upon it, by straightening the road, and by adopting a suitable form either of bridge or T-headed rail.

In thin seams the *tubs*, or waggons, must necessarily be low, and the wheels small, but even in seams of ordinary height, the convenience of keeping the total weight so moderate that the *putter* can readily place his tub on the rails when it gets displaced, and that the onsetter and banksmen can easily handle and run the tubs on the iron plates at the bottom and top of the shaft, give the preference in Northern practice to tubs weighing not more than 3 or 4 cwt., and carrying from 6 to 9 cwt. of coal. At Seaton Delaval and neighbouring pits, the tubs weigh 3½ cwt. each, and hold 11 to 12 cwt., but these require exceptionally strong men to handle them with the requisite rapidity. In the South, carts, or trams, of much greater weight, sometimes of iron, are often employed, carrying a weight of a ton; but, in such cases, the number is smaller, or conveyance and winding in the shaft are generally slower, and long delays are caused by getting off the rails.

The tub most generally used has an oak framing below, on which the bottom and sides, of ¾ inch or inch

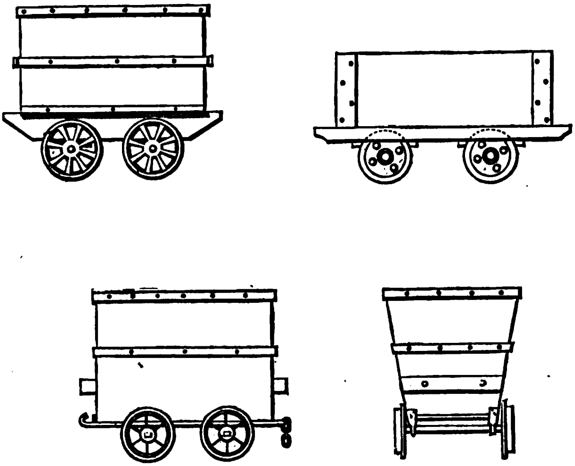

Fig. 23. Colliery tubs: 1 inch to 4 feet.

oak, or other strong wood, are attached, with corner pieces of iron to strengthen them, and a light bar of iron passing from end to end upon the framing, with a hook at one extremity and coupling chain at the other.

When the box part has vertical sides, the wheels are placed below, and are only 8 to 12 inches diameter; but when it is narrowed below, the wheels may be set outside, and are 15 to 18 inches diameter. They are generally fixed to the axle, but sometimes are, as well as the axle, made to turn. The form, in fact, must depend partly on the roads, and partly on the varieties of coal to be conveyed; but it would be manifestly inconvenient, in a colliery where a large traffic exists, to have carriages of different sizes and shapes.

For the purpose of bringing the weight low, and at the same time employing large wheels, M. Cabany, the ingenious director of the great collieries of Anzin, has constructed the modification of elbow-axle, shown in Fig. 24, which, he states, can be repaired at half the cost of the common elbow-axle. The mode of attachment of the wheel is shown in the figure, and the waggon is made to belly out above it, to increase the capacity on a narrow gauge.

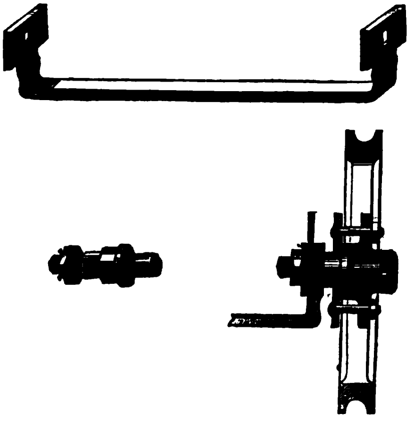

Fig. 24.

The main levels of a mine are generally carried too horizontally to allow the loaded waggons in one direction, and the empties in the other, to be drawn by a perfectly equal force. In order to have the resistance equal in both directions, the empty tub being 3 cwt., and the loaded one 12 cwt., and the friction $\frac{1}{80}$th of the weight, the inclination would have to be 1 in 133, and if the friction be $\frac{1}{60}$th, would be 1 in 100.

Mr. Wood found in his experiments that a horse dragging a carriage on a level railroad at surface will give a useful performance of $6\frac{2}{3}$ tons for 20 miles, or 133 tons for one mile per day, which forms a convenient maximum standard for judging of this—the most general means of conveyance, as carried out in various mines. Actual practical trials in several pits gave the following results:—

Locality.	Diameter of wheel. Inches.	Inclination of road.	Weight of tram.		Number of trams at once.	Tons per mile per horse.
			Loaded. Cwt.	Empty. Cwt.		
1. Elemore Colliery	12	1 in 130	12·5	4	14	29·75
Ditto . .	12	1 in 202	12·5	4	14	51·23
2. Hetton . . .	8	1 in 130	12·5	4	9	30·6
3. Andrew's House	10·25	1 in 222	13	5·3	11	54·15
4. Marley Hill. .	10	1 n 144	13	5		31·6
5. Springwell . .	10	Level.	11·5	3·5	6	15·26

Similar trials made in South Wales, where the work was done by drawing 3 to 7 larger trams, weighing when loaded 25 to 32 cwt. each, with wheels from 17 to 21 inches diameter, principally along water-levels, but in part along inclined headings, gave results of from 10 to 17·8 tons per mile as the day's work of a horse.

These surprisingly different amounts of useful effect depend in great part on the arrangements as well as the condition of the roads. If only a single line of rails, with passing places, be employed, much delay ensues; and if the distances travelled are short, and the stoppages at the termini more frequent, there must be a similar disadvantage.

In the 2nd and 4th examples above cited, the horses were particularly strong and in good condition, and yet the result falls so strangely short of what can be accomplished at the surface, as to give great weight to Mr. Wood's corollary, that it becomes daily more important to substitute, as at the surface so also underground, engine-power for the costly stable of 60 or 80 horses, which otherwise has to be maintained in the larger collieries.

When the coal, as usual, is worked from the mainways up the rise of the seam, if the inclination be as much as 1 in 30, inclined planes (*jinny roads,* or *jig-brows*) come into use, where by aid of a drum or sheave at the upper end, regulated by a brake, the loaded tubs run down by their own weight, and pull up the empty ones. Or the descent may be checked, and the ascent assisted, by the use of a counterbalance tub suitably loaded. The sheave for this purpose may, according to the nature of the work, be so fixed, by the aid of wooden props, as to be easily removed forward as the workings advance. This is, of course, a very inexpensive mode of conveying the coals, and is sometimes applicable for very long distances; although, for the avoidance of accidents, it is needful then to establish a very strict discipline as to signalling when the train of tubs is to be set running, and also to have side stalls cut out here and there for the safety of those men who may happen to be travelling the plane at the time. In the rudest of such inclines, a boy goes down with the sled, digging his heels into the floor by way of a drag; whilst in large and well-laid-out collieries, a regular series of such inclines, fitted with substantial brake drums, wire ropes, and friction rollers for them to run upon, vie with the best of inclined planes to be seen at the surface.

A contrivance of great ingenuity, Fowler's clip-pulley, has been most successfully used by the Messrs. Pease at the Upleatham mines for some years past, and appears to be capable of extended application in the working of inclines and engine planes in collieries also. Its advantages are that the rope need only to be passed simply over the periphery of the wheel, instead of being coiled or lapped round it as on a drum; that it then holds the rope more equably and advantageously without flattening the wires or grinding them against one another, and that it prevents a surging movement. The movable clips on the circumference, which embrace the rope, clutch it so tightly, that on a double incline, one set of tubs may be thrown off—as by the breakage of the rope—and yet it is capable of sustaining the other.

When, however, the coal has to be brought up by "down-hills," or roads driven below level, the labour thrown upon men at windlasses, or upon horses dragging carriages, is so great as to be inconsistent with extensive working; and, under these circumstances, it is usual to employ engine-power, either through the instrumentality of a rope passed from the surface down the pit (as at Monkwearmouth), or by fixed underground engines worked by steam transmitted from the surface (as at Killingworth), or generated in boilers near them,[*] or worked by compressed air.

If the inclination of a down-brow be not less than 1 in 28, the empty tubs, in running down, will drag out with them the rope from the drum of a fixed engine; but if it be less, they must be provided with a tail-rope passing round a sheave at the bottom of the incline, by which they will be hauled down again. These arrangements have long been practised, but not many years have elapsed since the last method came into use instead of horse power, for hauling the coals along the main ways which approximate to the horizontal. It is still only in the larger collieries, and those in which due care has been bestowed on the straightness and regularity of the roads, that this improvement has been introduced; but its value may be inferred from the fact that, in certain instances, as many as 70 or 80 horses, with their drivers, stablemen, &c., are dispensed with, and that a small fixed engine actually hauls along a nearly level plane of a mile and a half in length, trains of from 50 to 100 tubs at a time, at an average speed of 9 miles an hour. The employment of a tail-rope (usually of ½ to ¾ the circumference of the main rope) enables the train to be pulled over the undulations of gradient which cannot but generally occur even in the best underground roadways. Where these inequalities, and where curves interfere, they must be met by a sufficiency of rollers and of sheaves to protect the ropes from injury.

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[*] I owe to Mr. C. Tylden Wright the following example from a part of Shireoak colliery:—Inclined plane of 800 yards long below pit bottom, gradient 1 in 50; train of 25 tubs at a time, drawn at speed of 8 to 10 miles per hour by a ⅝-inch steel wire-rope, stretched by a 4-foot Fowler's clip-drum, and worked by two 12-inch cylinders, 2 feet stroke. Average cost, calculated from 30,000 tons conveyed in six months, one penny per ton, including wear and tear of rope and all labour.

In certain works the engine-road has been fitted with an endless rope, passing, of course, round sheaves at the extremities, and to which the trains of tubs are hitched or clamped at intervals. The comparison of this with the other method is still the subject of discussion; but, although very serviceable as contrasted with horse-work, it has not been shown* to attain to the amount of efficiency and economy exhibited by the engine "planes" of such collieries as Hetton, Seaton Delaval, Pelton, Black Boy, &c.

Regularity of action and compactness being two main essentials, the favourite engines for this purpose have two horizontal cylinders resting on bed-plates, and a heavy fly-wheel. But the form of the engine is hardly so important as the question of the mode of supply of steam, for the boiler-fires are in some situations a source of intolerable heat and of certain risk. It has been, however, shown in practice, that where it is inconvenient to place the boilers near the engine, they may be at surface; and if 8 or 10-inch pipes, properly clothed, are used to transmit it, there will be no substantial diminution in the elasticity of the steam in the receiver for the cylinders at the pit-bottom. In some instances the steam has been transmitted for above 1,000 yards, with a good result depending much on the sufficient diameter of the pipes; in others, compressed air has been forced for a distance of several hundred yards with a very trifling loss of pressure. And thus, by one means or the other, engine power becomes available to all those who, instead of dealing, as in the old time, with a few score of corves, have to run several hundred tons of coal, or in other words some 1,500 or 2,000 waggons, a-day, to the bottom of their shaft.

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* It must now be conceded that the Tail-rope Committee of the Northern Institute have proved excellent results from this system as applied in Lancashire, both with wire rope and with chain.

CHAPTER XIV.

RAISING THE MINERAL IN THE SHAFTS.

A FEW steps only, and of a simple kind, appear to intervene between the modes of slowly winding up small quantities of coal in the pits three centuries ago, and the vehement, yet well-disciplined extraction of the present day. But although the improvements have not been marked by any startling inventions, they have only been rendered possible by the simultaneous advancement of the other mechanical arts. And even now, it is solely under favourable conditions that the greatest eminence is attained, and we need but to travel a few miles into the hills from some of the noble collieries of Durham or of Lancashire to see, near the outcrops of the seams, little works carried on for local or *land* sale, where the apparatus, if not the ways and language of the people, will recall the days of a pristine simplicity.

As long as manual labour is employed for the raising, it may be of a few tons of coal per diem, the windlass and a round hempen rope are the means commonly used. In the hills of the West Riding of Yorkshire, a pinion on the crank axle works a toothed wheel on the barrel axle; and thus, by giving a slower motion, enables a man or two at the surface to raise a greater weight at once, and thus to keep even with several who are working below. With a depth of 30 or 40 yards, a more economical power has to be brought into play.

For horse work the invariable arrangement is to erect the "wheel-and-axle" kind of machine called a horse-*gin*, or *whim*, and consisting of a rope-drum built round a vertical axis, the foot of which turns on a stone or iron casting, and the head pivot of which is supported by a long "span-beam," resting at the extremities upon inclined legs. The horses are attached to one or both ends (according as power may be needed) of a strong horizontal beam, generally 30 to 36 feet long, which embraces the vertical axis close beneath the drum, which is 12 to 16 feet diameter. The ropes, passing off from opposite sides of the drum, are conducted over little guide-pulleys—*jackanapes*—to the sheaves set in the shaft-frame overhanging the pit.

Although very largely employed in metalliferous mines, the horse-gin is now seen in colliery districts only during the sinking of pits, or permanently employed at shallow works doing a very small trade. In the last century, before the introduction of the Boulton-and-Watt engine, it was in very abundant use in the English and Scotch coalfields, and we have, in the travels of M. Jars, an account of a powerful horse machine newly completed in 1765, for raising the coal at Walker Colliery, 100 fathoms deep. It was put in motion by eight horses kept at a sharp trot, and by means of a large horizontal toothed wheel giving a greater velocity to the rope-drum, lifted a corve of coals in two minutes: but, unfortunately for the result, the corve held only 6 cwt.! The simple gin, therefore, worked by two or four horses, remained the common machine for small depths.

It is only in districts more hilly than most of our coalfields that the streams flow with a sufficient fall to give a useful amount of water-power; but the convenient way in which the drum could be built upon the prolonged axis of a water-wheel led to that arrangement being commonly adopted by the middle of the eighteenth century, even where the supply of water had to be raised by a special Newcomen or atmospheric steam-engine. Many attempts were made to convert the alternating jerky action of this engine into the rotatory motion needed for winding, but to very little purpose. Smeaton meanwhile lessened the consumption of water, and thus reduced the expense. The wheels had been made with a double row of buckets, each row opening oppositely to the other, so that when motion had to be reversed, the supply of water was cut off by a valve and laid on the other way, and thus the wheel turned in the opposite direction. Smeaton applied reversing gear of strong toothed wheels to the drum, so that the wheel could always revolve in the same direction, and the turning of the drum only be reversed.

In Wales, another mode of employing water-power came into use, which is still to be seen at many of the collieries, as well as some of the slate quarries, where this cheap power is abundant. A large sheave fitted with a powerful brake is fixed above the pit-top, and has a rope or chain passing round it, to one end of which is attached an empty cistern carrying over it a waggon of coal, to the other a cistern which, when filled with water, is heavier than the loaded waggon and empty cistern together. Suppose now the former is at bank, the latter at the pit-bottom; the cistern is filled from a tank placed close by, and is regulated in its descent by the brake; when it reaches the bottom a self-acting valve is opened, which lets the water flow out, either to escape by the adit or to be raised by the pumping-engine: meanwhile the loaded waggon is taken off the empty cistern, and by the time the latter is filled with water from the same tank, the cistern at the bottom has been emptied and a waggon of coal placed upon it; and thus the action is reversed, and a cheap, although slowly-working machine, kept in reciprocating movement.

The chief forward step was made when Watt's double-acting engine, having the steam applied alternately on both sides of the piston, rendered it feasible to apply a rapid rotatory motion. In the smaller engines, and such, in fact, as are in work at the great majority of the collieries of our central and western districts, the motion is communicated from the main crank-shaft, through the intervention of toothed wheels, to a drum-shaft placed also horizontally, and to which a lower velocity is given. The ropes, or chains, wound in opposite directions on the drum, are carried over pulleys either down a single pit, or to two different pits, and thus, with their respective cages or skips, exercise a counterbalancing effect upon one another. This arrangement is particularly suitable to the slow winding of our midland districts, where the weight drawn at once is considerable, and where from its hanging free in the shaft, a great velocity would be dangerous.

But in the larger collieries, where rapidity is essential, two different forms of engine have for some years been in use. First, a large vertical cylinder, from which the piston rod acts *direct* upon the drum shaft, and the drum being often 16, 18, or even 20 feet in diameter at the first lap of the rope, communicates to the load a velocity of from 10 to 30 feet in a second. The second is the engine of two cylinders placed horizontally, acting also—it may be, *directly*—on the drum, and from their reciprocating action on the crank, introducing great regularity of motion.

As examples of some of the more powerful engines employed for these purposes at British works, may be mentioned,—

Monkwearmouth; vertical cylinder, 65¼ inches diameter, 7 feet stroke; depth, 286 fathoms, or 1,716 feet; wire flat rope; useful load, 4 tubs, with 9 cwt. of coal each; time of raising, 1¼ minute.

Dukinfield, Cheshire; No. 1 pit; vertical cylinder, 60 inches diameter; stroke, 7 feet; low pressure; flat wire rope; load, 4 tubs, with 8 cwt. of coal each. No. 2; cylinder, 48 inches diameter; stroke, 6 feet; high pressure; drawing depth, 678 yards, or 2,034 feet; time, 70 to 90 seconds.

North Seaton; vertical cylinder, 60 inches diameter; stroke, 7 feet; depth, 124 fathoms; flat wire rope; load, 4 tubs, with 50 cwt.; weight of steel cage, 25 cwt.; time, 35 seconds.

Rose-bridge, Wigan; two coupled horizontal cylinders, 36 inches diameter, 6 feet stroke; depth 806 yards (2,418 feet), flat steel rope; load, 4 tubs, or 28 cwts. of coal; wire rope guides; time 50 seconds.

Kirkless Hall (*California pit*), Wigan; two coupled 24-inch cylinders, vertical, 5-feet stroke; round steel rope; conical drum; depth, 345 yards, or 1,035 feet, two-decked cage, with 4 tubs, carrying 24 cwt. of coal; time in shaft 40 seconds.

Seaton Delaval; two horizontal cylinders of 36 inches diameter; 6 feet stroke; high pressure; depth, 112 fathoms, or 672 feet; flat, 5 inch wire rope; load, 4 tubs, with 11 to 12 cwt. each; weight of iron cage, with its chains,3 tons; time, 30 seconds.

Navigation Pit, Aberdare; two oscillating cylinders, 43 inches diameter; 6 feet 2 inches stroke; depth, 365 yards, or 1,095 feet; round wire rope, 2 inches diameter, on conical drum; load, 2 large tubs, 17 cwt., with 47 cwt. of coal; cage and bridle chains, 2 tons, 3 cwts.; total weight, with rope, at bottom of pit, 9 tons; time in shaft, 46 seconds.

The high velocities which are thus attained in shaft-work, by means of which from 500 to 1,000 tons of coal are drawn from a single pit in a day, have been rendered possible only by the use of guides or conductors, which insure smoothness of movement and prevent collisions. Mr. Curr, of Sheffield, already mentioned for his valuable innovations, introduced at the end of the last century wood conductors for guiding the corves, by aid of which he asserted that he could draw from 140 yards depth in half a minute. Yet for years he found but little response; they were applied at a few of the midland pits, and about 1827 by the late Mr. Holwey, at Welton Hill, near Midsomer Norton. In the north they began to make their way between 1835 and 1840, and are now universally employed, as essential to economy and to the safety of the men.

The conductors in general use are of wood (Memel pine) about 4 inches by 3, attached to *buntons*, or cross-pieces, fixed across the pit at intervals, and are commonly only two in number, one on each side of the cage, and costing, with labour, 10*s.* to 14*s.* per fathom. In some instances a pair of vertical iron rails are employed; in others, lengths of angle-iron, similarly attached to buntons. In Lancashire many pits have been fitted with a continuous round bar of iron, fixed at the pit-bottom, and screwed up to the head-frame, the cross-bar of the cage having a ring at each end which runs upon the rods. An inferior plan was that of stretching down the pit a single-link chain, now superseded by suspending strong wire ropes* kept in place by heavy weights at the pit bottom, and giving a clearance of 20 to 24 inches between the cages.

One of the important shaft-fittings, upon this method, is the cage, or chair, for the reception of the tubs or trams, which simply traverses up and down the pit. It is almost invariably constructed of malleable iron, and, since lightness is highly desirable, as small as possible for the weight it is destined to carry. For a single tub a cage of 5 or 6 cwt. will suffice; for two, whether to be placed side by side or one over the other (a 2-decker), 9 to 10 cwt. At Monkwearmouth the 4-tub-cages weigh as much as 24 cwt.; others no less than 3 tons, including their tackling-chains. Cages of combined strength and lightness have of late been advantageously made of steel.

The slide parts of the cage, of thin wrought iron, which loosely fit to three sides of the wooden conductor, are applied both at the upper and lower bar of the framing, and are a little bell-mouthed upward and downward to allow them to slip more freely over inequalities. In order also to keep the tubs from shifting during their transit, a simply contrived latch is always applied either on the floor of the cage or at the ends of a rod passing through its upper bar. And when the weight

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* The stout wire-rope conductors employed in many deep pits in Lancashire are found to be most serviceable even at the highest velocities.

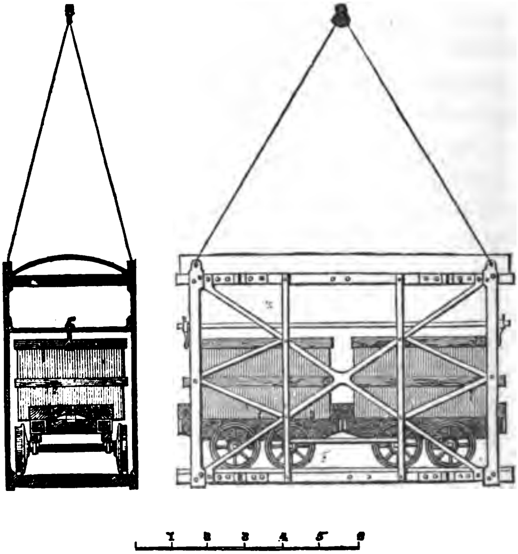

Fig. 26. Single-deck iron cage, Newsham, for rolled iron guides.

reaches the surface, duly signalled on its approach by a bell ringing in the engine-house, and by some visible mark attached to the rope, the cage is lifted with its floor a little above the plane of the bank at which it is intended to rest, and then allowed to drop on to the *keeps.* These latter are the heads of an arrangement of counterbalanced levers, which offer no obstacle to the ascent of the cage, but by a single movement of the hand, or automatically, are made to protrude and catch it in its descent. The moment that, at a lively pit-mouth, the cage bottom touches the keeps, the landers have already got hold of the full

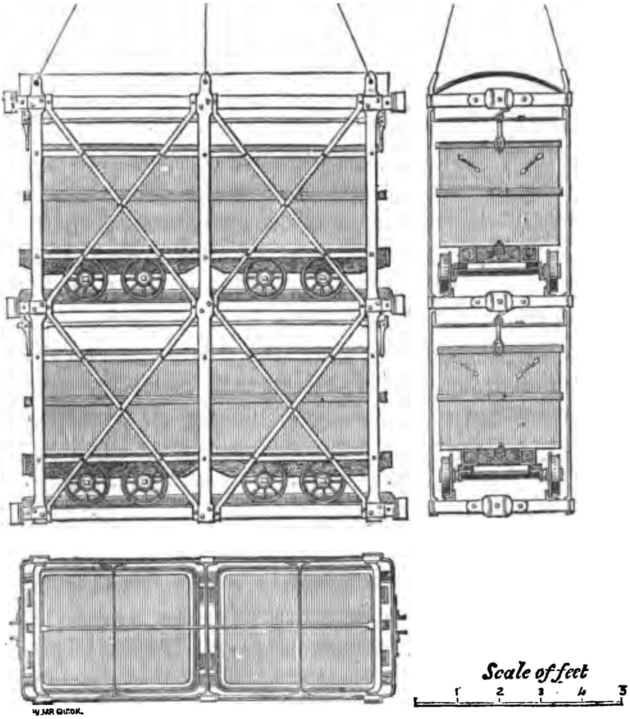

Fig. 27. Steel cage, North Seaton, with four tubs. Elevations and plan.

tubs to pull them on to *terra firma*, or are forcing them out with the empty ones which they are pushing in to take their places. On the iron-plates with which the staging about the pit-top is floored, the waggons are hauled off, up goes the cage with a jerk a few feet, and anon plunges down again into the gloom; whilst the men are rushing forward with the empty tubs prepared for the fellow-cage, which in a few seconds flies up by the other side of the pit.

When the cage is two-decked, or, as sometimes in Belgium, has three or four compartments one above the other, the landing process has to be repeated at the same level, or, for the purpose of saving time, may be carried on at two different levels on the staging, whilst the loading is similarly performed at the bottom. It is in this way that a very neat system is adopted for running in and out the eight tubs which form the load of the great 4-decked cage of the Grand Hornu Colliery, near Mons, a cage weighing itself, with its protecting cover, about 2,692 lbs. English.

The single-link chains, and the round hempen ropes of former days, survive only at rude and petty works. Elsewhere they are succeeded by flat ropes of hemp (*bands*), by the ponderous flat chains of three links used for slow drawing in the Staffordshire district, or by wire-rope, either flat or round. Iron wire was applied to mining purposes in the Hartz mountains, and then in Hungary and Saxony, before it was tried in England, and its cheapness and lightness, as compared with hemp rope of equal strength, obtained for it a great, but by no means exclusive success. The desirable quality of lightness has been pushed still further by employing ropes of steel wire, but not hitherto to any great extent, although Mr. Tylden Wright informs me that his flat iron wire ropes, weighing 27 lbs. per fathom, have been replaced by flat steel of 16 lbs., and (in the upcast pit) by round steel rope of 13 lbs. to the fathom, the weight of coal in each case being 28 to 30 cwt.; and that the round ropes have been working for two years, whilst the flat iron and steel ropes seldom admit of more than 14 months wear.

The flat ropes have been largely employed, in consequence of their easing the engine by coiling one lap over the other, and thus forming a counterbalance as the cage ascends or descends, giving the fullest leverage to the engine at the time that the maximum weight is being lifted, *i.e.*, when the loaded cage starts from the bottom of the pit. But the greater wear and tear has given rise within the last few years to the introduction of round wire-ropes, coiled—some upon cylindrical, others upon conical drums. In the instance just quoted, the drum runs from 16 feet at the small end up to 20 feet diameter; and if due care be taken to wind the rope on at first very tightly, and to give such an inclination as shall guard the coils against slipping, these drums are found to work admirably.*

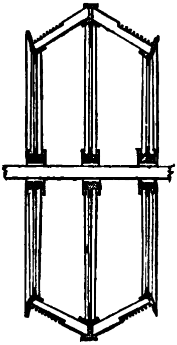

Fig. 28.
Conical drum in section.
Scale, 1 inch to 10 feet.

In the deeper Belgian collieries, flat ropes made of the aloe fibre (much employed for the same purposes in Mexico) are preferred. The disadvantage of this material would appear to be the great weight, since with about 15 per cent. of tar, the ropes used at the Grand Hornu weigh from 12 to 19 lbs. per metre of 3·28 feet English. They are stated, however, to be extremely strong, trustworthy, and durable. As a further means of counterbalancing the great weight of rope to be lifted with the full cage, there is, in most of the Northern collieries a counterbalance chain attached to the drum shaft, which passes in the reverse direction to the rope over a pulley, and has, appended to the end of it, a quantity of excessively heavy links of iron, which repose at the bottom of a pit, 30 or 40 yards deep, when not required to be in action. When, however, the descending rope begins to preponderate, they are gradually lifted into the air, and thus, when the full cage begins to be lifted, aid, with their great weight, the effort of the engine in accomplishing the heavier portion of its work.

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* In several instances with a maximum diameter of 24 to 30 feet conical drums have been constructed with an iron channel or scroll f the reception of the rope.

The pulley-frames, or *head-stocks*, intended for the working of a single *band* down a pit, and thus often

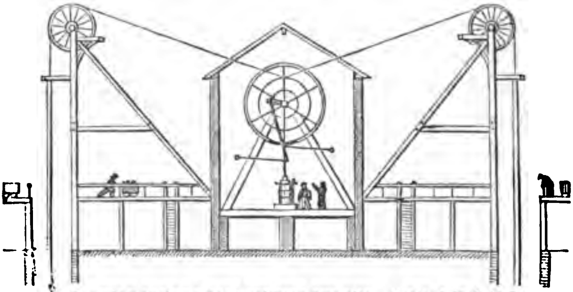

Fig. 29. Drawing-engine placed between two pits. Scale, 1 inch to 50 feet.

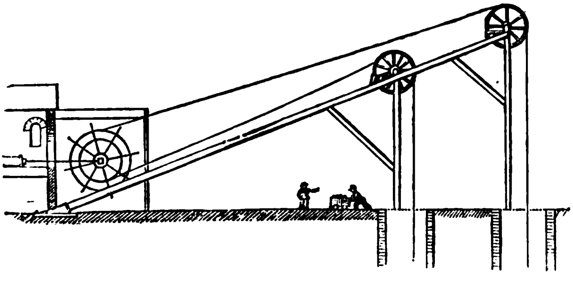

Fig. 30. Engine on one side of a pair of pits. Scale, 1 inch to 50 feet.

placed one on each side of the engine, as commonly arranged in the midland districts, are a comparatively simple framing in a triangular form, composed of two uprights and two back-legs, supporting a sheave or pulley of cast iron, 6 to 9 feet diameter, at the height of from 20 to 30 feet above the ground. When intended for rapid winding, these latter are generally replaced by pulleys of greater diameter, from 10 to as much as 20 feet, and having the spokes made of light wrought iron rod and only the socket and rim of cast iron. When two bands are to be worked, the pair of pulleys are set upon a framing of greater breadth, which often has a general rectangular form, steadied by back-legs strutted either against the ground or against the engine-house. But the varieties in form are so numerous that it would carry us beyond our limits to do more than refer generally to them. A noteworthy, but expensive, modification is that at Seaton Delaval, where the timber framing is replaced by beams of $\frac{3}{8}$ths inch wrought iron, riveted at the corners with angle-iron.* Cast iron has been employed in Staffordshire for small frames, but it is not to be relied upon.

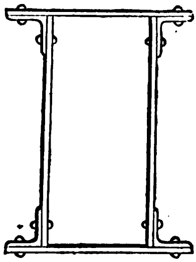

Fig. 31. Plan of iron uprights.

With all the precautions taken to secure good engines, careful men, and trustworthy ropes, two kinds of accidents occasionally occur, which, as in this country the men are invariably lowered and raised by the same machinery, give rise to a peculiarly harrowing loss of life. One of these is the *overwinding*, which brings the cage violently up against the pulleys overhead, and thus breaks the rope. And, as with the large drums now in use, a single stroke of the engine raises the cage 60 or 70 feet, it will be seen how needful it is to have a careful engine-man, and machinery under perfect control. Overwinding is guarded against partly by having the pulley-frame high (from 30 to 60 feet), partly by the signals which tell the man when to moderate his speed, and partly by efficient brakes; and of late steam brakes have often been added to the engines, which in some cases are self-acting, and come into play by admission of steam into a special cylinder as soon as the cage passes a certain point in the guides.*

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* Many patterns of iron frames have now been introduced. 1880

The second class of accident is from the simple breakage of the rope, and whilst, in most cases, it is guarded against only by keeping in employ the best materials, and carefully overhauling the rope, it has been the subject of a number of inventions, to which the name of safety-cage, in French *parachute*, has been applied. As early as 1846, Mr. Fourdrinier had practically tested in North Staffordshire an ingenious arrangement by which, on the breakage of the rope, a wedge was, by the action of a spring, inserted between the wooden guide and a part of the cage, so as to bring the latter immediately to a stand-still. In 1850 and 1851, I saw a number of them applied by sundry colliery viewers, who, two or three years later, had, after fair trial, unshipped them all, mainly for the reason that they were apt, in quick winding, when the rope surged or slacked, to come into play when not wanted, and thus to introduce a new source of delay and danger. In fact, to the present day, this same objection holds good, more or less, to all the varieties that have since been proposed; and, along with the common dislike of trusting to a spring for setting it in action, militates against their general adoption by the coal trade.

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* See also Chap. XVIII., p. 239.

Two varieties, it is true, were shown at the Exhibition of 1862, which dispensed with springs, Paull's and one of Nyst's, of Belgium; but neither of them was thought satisfactory by the Jury.

The remainder of the safety-cages are chiefly divisible into those where two levers are made to thrust outwards against the conductors, and those where clutches embrace the two sides of the guide rods. Of the former kind is that of Fontaine, which has been successfully applied in the great collieries of Anzin. Of the latter, we can only mention White and Grant's, largely employed in Scotland; Aytoun's, Nyst's (fitted to trapezoidal guides), Jordan's, which grips firmly without the use of sharp teeth; and Owen's, Fig. 33, which has been applied in many of the Lancashire pits, and has actually saved numerous lives.

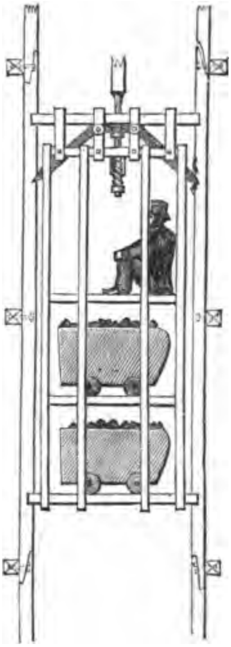

Fig. 32. Fontaine's parachute as it appeared at the colliery of Boussu, when the flat wire-rope broke with a weight of 2 tons.

The apparatus of Mr. Calow, of Derbyshire, Fig. 34, is noticeable for the ingenious manner in which he brings a single spring to bear on the clutches, not when the rope is merely slacked, so as to run out faster than usual, but only when the cage begins to descend at the velocity of falling. The spiral spring, held in a state of compression between a weighted cap above it, and the part of the cage below it, from which the cap is separable, no sooner finds its foundation gone by the commencement of fall, than it flies into action, lifting its cap and pulling the levers which close the clutches.*

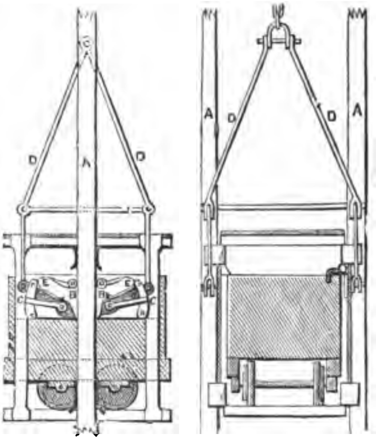

Fig. 33. Owen's safety cage.

A, the conductor rods.
B C, the toothed levers connected by the rods D D with the rope.
B E, the spring which, if the rope breaks, forces down the upper end of the lever.

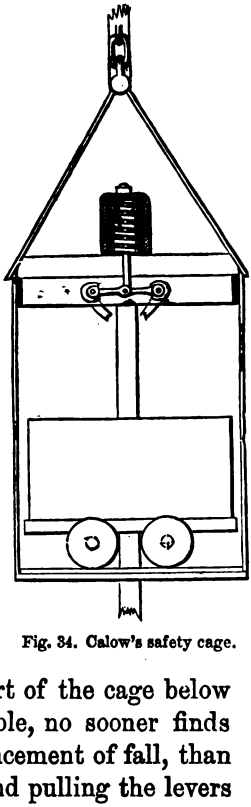

Fig. 34. Calow's safety cage.

The question of the advisability of employing any form of safety-clutch yet invented, is by no means settled. Many of the most experienced colliery viewers, both at home and abroad, hold to the opinion that they substitute one danger for another; and that, what with the inconvenience of their operating when not required, the danger of trusting to springs amid the dust and wet and rust of a shaft, and the tendency to induce neglect of the proper condition of the rope, it is safer to trust to careful engine-men, the best materials, and caution in not running a rope too long, or omitting to have it frequently examined.

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* Models of a great number of the safety-cages which have been in practical operation are open to inspection in the Museum of Practical Geology, Jermyn Street.

Many of the above inventions are coupled with an apparatus for disengaging the cage if overwound, and thus bringing it to a standstill against the guides; and these form, doubtless, a very useful adjunct.

A cover, or *bonnet* of sheet iron, is now very generally added to the cage, to protect the men against falling materials; and with the addition of sliding gates at the shaft-top, which are lifted when the cage comes up, but guard the brink of the pit when the cage is down, are safeguards against many of the accidents so rife in connection with shafts.

Those who are connected with metalliferous mines would like to see one of the pits of every coal-work fitted with a ladder-way, to give egress to the men in case of accident to the winding machinery; but though commonly employed on the Continent, ladders are quite unusual at our British collieries.

A safe and very economical mode of putting the men up and down the shafts is the *Fahrkunst*, or man-engine, a reciprocating rod or pair of rods, fitted with steps, by which the traveller is lifted from 8 to 14 feet at a stroke, and by which an entire pit's crew of 400 or 500 men may be conveyed in little more than an hour.

In Belgium and Westphalia, as in our Cornish mines, they are in common use; and, from a long experience, I can testify to their comfort and security; but in our coal districts, a strong feeling in favour of the rope prevails, by which, although one party of men passes through the shaft more rapidly, the passage of the whole complement occupies the engine much longer; whilst the annals of colliery working supply us with too many sad instances of the dangers which attach to this system.

CHAPTER XV.

DRAINAGE AND PUMPING.

In no respect do collieries differ more from each other than in the quantities of water which they encounter, either in the winning, or in the subsequent working of their mineral. In one case, a retentive clay cover may prevent the access of surface water, which in another may pass in abundance through a sandy or a gravel alluvium. In certain districts, water-bearing measures of an almost fluid consistency must be passed through, whilst in others, the comparatively tight coal measures may at once be entered. Frequently the strata above and below the coal are so compact as to render the workings actually too dusty and dry; but instances are common enough in which water makes its way through the roof stone, or through the coal itself, and adds difficulties and expense to the whole of the operations. In a former chapter, we have seen that by the process of *tubbing*, the water met with in the shaft may be so effectually excluded, as even to admit of a mine being worked dry beneath heavy feeders; but it too often happens that either from the conditions of the place being unfavourable to the process, or from its not having been attempted, a costly system of pumping has to be unremittingly maintained.

Up to the beginning of the present century there were many districts in which comparatively shallow collieries were drained by means of adit-levels, or *soughs*, often driven for a long distance from lower ground. But, in proportion as these superficial workings have been exhausted, it has become necessary to follow the seams to greater depths, and there are but a few hilly regions left, such as South Wales and Dean Forest, where some of the works still enjoy the advantage of free drainage.

Before the practical introduction of Newcomen's steam-engine, the modes of removing the water from under-level excavations were by the application of horse power or of water-wheels to an endless chain with buckets, to drawing-pumps, to the rag-and-chain, or to winding of the water in barrels or ox-skins. Agricola gives us, in 1550, an accurate description, with drawings, of many varieties of apparatus worked by tread-wheels, by horse-gins, or by water-wheels of 15 to 30 feet diameter, which show that very little advance was made between the period of his observations and the commencement of the 18th century. Nay, it is clear that until of late years, many of our mines still laboured under the same disadvantage as of old in their pump-work, viz., that it was supposed to be necessary to restrict the height of a lift of pumps to the 32 feet through which water can be raised by atmospheric pressure. The several contrivances above mentioned answered their purpose as long as the pits were very shallow, but their difficulties increased rapidly with depth (a condition of mining work often overlooked by inventors), repairs were constantly needed, and, "when a joint-pin gave way, the whole set of chains and buckets fell to the bottom with a most tremendous crash, and every bucket was splintered to pieces." *

When pumps were employed, of which the one raised water, about 30 feet only, to the next lift above, the moving parts had to be so multiplied, that things were unnecessarily crowded in the shaft; first-cost and subsequent maintenance were needlessly heavy, and all the difficulties were greatly augmented with the increase in the volume of water to be lifted.

These common drawing or "suction" pumps had to be converted into the more useful drawing or bucket-lifts of mines, by the simple expedient of increasing the height of the collar above the piston, or in other words, making the bucket-rod work inside a column of pumps, or *trees* (as they are often termed, from being originally of wood), and lift the water above it. Applied in this manner, the length of the lift becomes only a question of strength of materials, and it is commonly extended to 50, 60, or 80 yards.

The woodcut, No. 35, will show, in section, the bucket in its *working barrel*, the rod extending upwards with the column, or trees; below it is the *clack*, or

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* Fossil Fuel, p. 196. A singular pumping-machine recalling this old apparatus was still, in 1857, to be seen at the little colliery of Coal Barton, near Frome, where 50 fathoms length of 8-inch pumps were worked by a fall of water passing 26 yards down a pit, and utilised upon a chain with buckets of sheet iron lapping over wheels above and below.

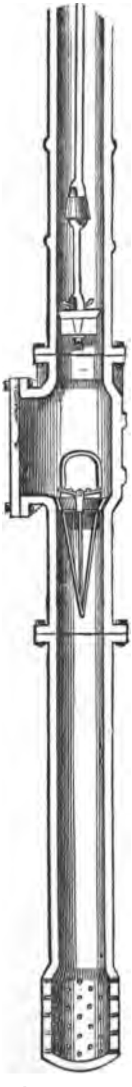

Fig. 35. Bucket, or drawing lift.

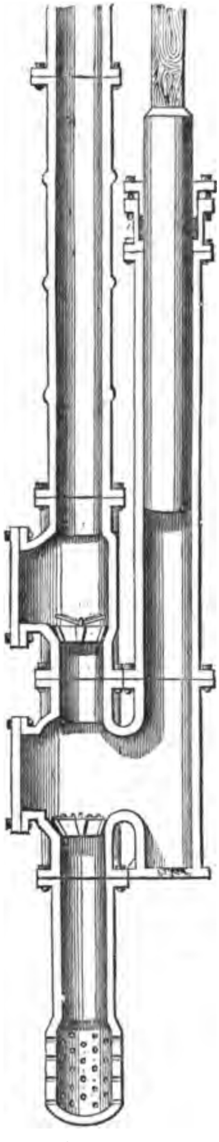

Fig. 36. Plunger lift

valve-piece, resting in its seat, and capable of being removed either through the *clack-door*, or sometimes, in case of accident, by being fished up with a hook passed down through the column on removal of the bucket-rod. The lowermost portion is the so-called *wind-bore*, or *snore-piece*, where the holes in the bottom, generally covered by the water of the cistern or the sump, are of such size as to prevent the entry of chips or stones. The joints of the various lengths, and that between the door and the clack door-piece, are made tight by the intervention of a thin layer of some soft material, as tarred flannel, caoutchouc, &c., and screw bolts and nuts. The action of this pump is easy to follow: at every up-stroke of the rod, the water will rise through the clack, and the column of it standing above the bucket will be so raised as to deliver, at the top of the lift, a quantity measurable by the diameter of the working-barrel and length of the stroke. Should the pumps be going "in fork," or the water have receded below some of the holes of the windbore, the ebullition of the water will show that air is being drawn, and that the full quantum of water is not being raised.

A few specialities of the bucket-lift may be noticed. When the water is saline or acidulous, and corrodes the iron, the working-barrel, ordinarily of cast iron duly bored, is sometimes made of brass or gun metal (as, indeed, it very often was in earlier days); or, as in some of the copper mines in Cornwall, the whole of the pump-work may need to be lined with staves of wood, carefully fitted like an internal cask, to prevent the rapid destruction which otherwise ensues. During the king of pits, and where sand finds its way to the , the leather with which the bucket is geared is rapidly cut to pieces, and the water ceasing to be properly lifted, the bucket has to be changed. In very bad cases this may take place, not merely several times a week, but even every few hours, and the time and cost expended in the operation are very serious. Metallic and gutta percha packing have been largely tried, but without establishing a general superiority.

The clack is much more slowly worn, but it is nevertheless often a subject of trouble if the water be quick and rises above the clack-door before the change be made. When in such case it refuses to act, and sticks fast in its seat, it must either be drawn out by main force, or a second clack may be dropped upon it, and the water thus lowered. In recent instances, very important services have been rendered by professional divers, employed to put to rights a lost lift. At Messrs. Fletcher's Clifton pits, Workington, and in South Wales, the work has been thus satisfactorily done by aid of the diving apparatus, under 30 or 40 feet of water.

To return to the action of the pumps. At every upstroke it will be seen that the engine has to raise the rods, or *spears*, and their connections, as well as the entire column of water contained in the lifts; and in order to obviate the enormous strain thus occasioned, it was early found desirable, in the deep mines of Cornwall, to substitute for the buckets a forcing arrangement in all but the bottom lift. This was perfected by Captain Lean, in 1801,* by the introduction of the *plunger pole*, or *ram*, working through a stuffing-box into a plunger case of bored cast-iron, and forcing at every down-stroke the water upwards through an upper clack, and the clear column of pipes above it. The working of this method will be evident from the sectional woodcut, No. 36.

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* The plunger had, however, been at work in the United Mines several years before this date, erected probably by Murdoch.

The great advantage hence derived over and above the much smaller degree of wear and tear, is, that the engine has simply at each stroke to lift the rods and plunger poles. These, then, in the down-stroke, by their own weight, descend and force the water before them. And inasmuch as the weight of the rods is far more than sufficient in a deep mine for this purpose, they are in part counterbalanced by beams (balance-bobs) placed some at surface and some at intervals in the shaft, each laden with 15 to 20 tons of old iron.

Thus, in the mine of Tresavean, at a shaft 348 fathoms deep from surface, the 86-inch cylinder engine raised a weight of rods, plungers, and sets-off, for nine lifts, of 67 tons, 3 cwt. The main beam, with its gudgeons, connections, &c., 50 tons; four balance-bobs, 60 tons; the four loaded balance boxes, 80 tons; or, altogether, besides the weight of water in the drawing lifts, about 260 tons, to be set in motion at every stroke of the engine.

The arrangement in Cornwall is universally the same. From the end of the main-beam, projecting over the engine shaft, a single rod passes all the way down to the bottom or bucket-lift. Employed in its maximum strength at the surface, where it has the full weight to sustain, it is then tapered or diminished downward according to the diminution of the strain by which it is affected.* At the requisite intervals the plunger poles are attached to it by *sets-off*, bound to it by strong staples of iron. The several lengths of rod, generally from 40 to 70 feet in length, are connected by the aid of strapping plates of hammered iron from 9 to 12 feet long, on opposite sides of the rod, bolted through it with screw bolts. At moderate distances apart, stays are placed across the shaft, which guide the motion of the rod, and iron rollers are added where it deviates from the perpendicular. At intervals, too, very strong beams are fixed in the shaft as *catches*, to prevent the fall of the rods downwards, as well as *indoor catches*, to prevent damage to the engine in case of the rod breaking at a shallow point, and thus being suddenly relieved of its great weight. In this manner the gigantic pumps employed in some of the mines are worked with such perfect ease and smoothness of action that you may stand near them in the shaft and not be aware, except by seeing, that they are in motion.

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* Thus, in a deep mine, a main rod of 290 fathoms long is made, for the first 120 fathoms of two 12-inch square Riga balk, and afterwards one of 15-inch balk, decreasing to 14-inch and 12-inch.

I have thus dwelt especially on the Cornish methods, because the necessity for economy and the competition between the engineers in that district have brought the pit-work to a higher degree of perfection than is to be seen elsewhere. When tested by the work done for a given sum of money, it contrasts remarkably with the rattle and concussion, the heavy cross-heads, and the greater complication of rods that are often noticeable in other mining regions, even though the excellent invention of the plunger may have been adopted.

We have now to examine into the mode of applying the power which is to keep the pumps in action. I may omit to describe the means of setting water power to work pumps of the above description, for although often employed with advantage for metalliferous mines, it seldom comes into play in collieries. Both in the commencement of operations at a difficult sinking, and afterwards as a permanency at small or lightly-watered pits, the double-acting rotary engine is commonly used. If the water is to be drawn at times when coal is not to be raised, the usual ropes or chains have attached to them water-barrels, *cowls*, or *ringes*, which will carry from 10 cwt. to a ton of water, and are emptied on

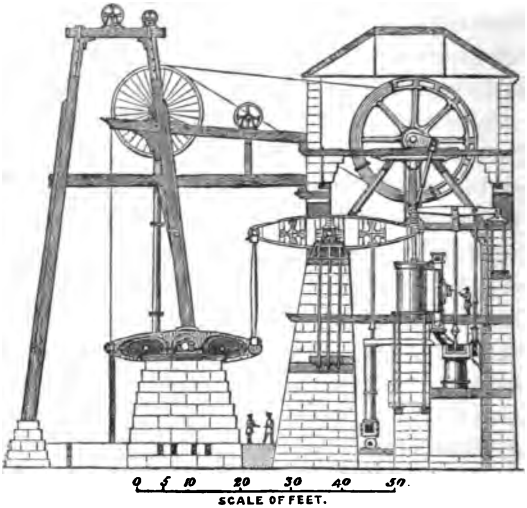

Fig. 37. Engine and apparatus for winding and pumping, Cambois, Northumberland.

reaching the surface by means of a self-acting valve placed in their bottom, or by being capsized by the lander. When pumps are to be worked, it is usually by sweep-rods passing from the crank on the main shaft to quadrants or bell-cranks at the shaft mouth. Engines of this class, whether worked by high or low pressure steam, are suitable enough for temporary or auxiliary purposes, but must be superseded in deep or heavily watered mines by special pumping engines. In some few instances the combination of drawing and pumping may be seen on a large scale, as in Fig. 37, representing an engine of 65-inch cylinder and 7-feet stroke, Cambois, Northumberland, which, though ultimately intended for drawing alone, is at present, during the sinking of the shaft, working the pump rod by the intervention of, first, a built wrought-iron beam, and, secondly, a beam of cast metal.

The engines intended for serious pumping form a subject of the highest importance in mining, and as the value of the best kinds is still but imperfectly understood, it is desirable to take an accurate view of the results which have been obtained from them.

We have already, in Chap. I., followed the improvements of the steam-engine with reference to the employment of coal as a motive power, and have seen that Newcomen's atmospheric engine (of which a very few specimens are still left) was succeeded, soon after Watt's patent of 1769, for the separate condenser, by various improved forms. The comparison between different constructions which then became needful, was made by calculating the *duty*, or number of pounds of water raised one foot high by a bushel of coal. When Smeaton commenced his modification of the atmospheric engine, the average duty about Newcastle was 5,590,000 lbs.; in 1772 he erected one at Wheal Busy, which attained 9,450,000. The same great engineer acknowledged that Watt's engines, which came out between 1776 and 1779, would perform double the duty of his own, and some of them were tested to do nearly 19,000,000. The average, however, of Watt's engines in Cornwall gave a duty of 17,000,000, and when

20,000,000 had been attained in the engine at Herland, that shrewd philosopher pronounced the work perfect, and stated that further improvement could not be expected. Left, however, to themselves, by the expiration of Watt's patents, and the withdrawal of his agents from the county, the Cornishmen after a few years organized, in 1811, a system of monthly reporting the engines, with their conditions of work, and the duty accomplished. Within a space of some twenty-five years marvellous results were produced by the emulation thus aroused among mine-captains in the arrangement of their pit-work, and among engineers in the devising of improvements in boiler and engines.

As some of the modifications to be specially cited are, (1) Trevithick's tubular boiler for generating high pressure steam, where the fire is applied at the large end of the tube, and the heated air made to pass through it, then beneath the boiler or outer tube, and afterwards along its sides; 2ndly, the expansion in the cylinder of the high-pressure steam by closing the inlet valve at ½, ⅓rd, ¼th, or even ⅙th of the stroke, whereby from 41 to 60 per cent. of the fuel is saved; and 3rdly, the addition of a steam jacket or outer case to the cylinder, so protected by a brick wall, casing of sawdust, or other clothing, that the internal space is occupied by steam of a temperature but little below that in the cylinder.

From an average duty of 17,000,000 performed in Watt's time, the Reports published by Lean show an amount of 28,000,000 attained in 1823, and of no less than 60,000,000 in 1843, whilst the best engine then tested had actually given an average duty of above 96,000,000! The most remarkable case on record is that of Austen's engine of 80 inches diameter, erected by

Mr. William West, at Fowey Consols Mines, and which, on being reported in 1834 to give a duty of nearly 98,000,000, was the occasion of a searching investigation and of a practical experiment, conducted by other engineers and mine agents, formed into a committee.* The shaft was at that time 131 fathoms below the efflux point of the water, the lifts of 15 inches diameter for the three upper, and 10½ inches for the two lower ones; the length of stroke 9 feet 3 inches, the pressure at the boiler 36½ to 45 lbs. per square inch. The astonishing result was, a declared duty for the twenty-four hours of experiment, of 125,000,000!

On taking the average duty all through the year at 91,672,210, we find that, as burnt in this way, one ton of coal will do the work of five tons in Watt's engines, and will raise for 100 fathoms in height as much as 367,000 gallons, or 1,638 tons of water; whence, taking coal in Cornwall at an average price of 15*s.* per ton, the fuel costs one farthing to raise 2¼ tons of water 100 fathoms. The coal consumed for the long single-tube boilers of the Cornish engine is Welsh, shipped from Llanelly and Swansea, mostly small, and weighing 94 lbs. to the bushel. The combustion is very slow, but so perfectly effected, that a few years ago scarcely a puff of smoke was to be seen between one end of the county and the other. Of late it is true that a black pennant is occasionally visible, and the blame is laid upon inferior coals. But, at the same time, it is observable, that a very small number of the engines are reported, and the average duty has deteriorated; and thus, whilst the shareholders grudge the guinea or two per month for engineer's or reporter's fee, they pay heavily in increased coal-bills.

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* Similar experiments by a committee had shown, in December, 1827, that Woolf's engine, at the Consolidated Mines, gave 63,663,473 lbs. duty, and Grose's engine, at Wheal Towan, St. Agnes, in 1828 87,209,662 lbs.

Among the most experienced of our mine-engineers in Cornwall, may be mentioned Captain Grose, Messrs. Harvey and Co., of Hayle, Messrs. Hocking and Loam, and Mr. West, of St. Blazey. Engines on a similar construction have been built elsewhere, at Messrs. Fairbairn's and many other works, both at home and abroad. But there has been wanting a fair system of reporting the results obtained; and when we see the great strides which accompanied the recording and publishing of the details in our western counties, it appears most desirable that such reports should become more general, and should include coal districts, in which we too often have to witness miserable exhibitions of neglect, extravagant use of fuel, and great wear and tear of materials. To compare a bad case with a good one, I have watched a large pumping engine in the north, which raises water from 105 fathoms deep, in 12-inch lifts, at 7½ strokes per minute, with a consumption of 20 to 25 tons of slack *per day*. A similar amount of work is done by an average Cornish engine with from 2 to 2⅓ tons. The coal is, doubtless, in the former instance inferior, but the result shows that there *are* engines in the country consuming upwards of ten times the quantity of coal that is needed for the work accomplished!

At the beginning of the century, it was proposed by Bull, to omit the heavy beam, or *bob*, which constitutes a great part of the dead weight of the common pumping engine, to place the cylinder over the shaft, and connect the piston-rod, working through the bottom, directly with the main rod of the pumps. The Bull-engines have been erected at many mines, but have failed to compete with the others. Of late years, several have been established at collieries in this country and abroad, but their effective performance is doubtful. Another modification is just now in fashion in the coal districts, although condemned, after long experience, in Cornwall, viz., that of inverting the cylinder and placing the beam below it. But the piston-rod can hardly upon this system be so well lubricated, nor the stuffing-box kept in equally good condition, and the asserted saving in the building of the engine-house seems at best to be a very questionable piece of economy.

The fearful loss of life occasioned by the fracture of the main beam at the Hartley Colliery, has been the cause of further attention paid to that part of the engine; and several methods of substituting wrought for cast iron have been applied. At Clay Cross, the beam of the new 84-inch engine is formed of two slabs of rolled iron 36 feet long, 7 feet deep in the centre, and 2 inches thick, the two braced by strong cast-iron distance-pieces bolted between them, the whole beam weighing 32 tons. At North Seaton and Cambois, near Newcastle, and at East Caradon, and other mines in the west, beams have been variously built of boiler plate and angle-iron; but it yet remains to be seen, what mode of construction will best ensure that rigidity which cast iron, with all its faults, must be acknowledged in a high degree to possess.

CHAPTER XVI.

LIGHTING OF THE WORKINGS.

The collier, in descending to his work, seldom needs to carry a light through the shaft. A few seconds, when the machinery is good, or minutes where it lacks power, are sufficient to land him at the bottom, either in the dense gloom of a pit eye, rendered barely visible by a candle, or a safety-lamp, or, according to the circumstances of the colliery, in a busy scene of activity, well lighted by oil lamps or even by gas. Here, or at some station not far in-bye, he will light up, and, after a little delay, in order to accustom the eye to the darkness, proceed on his inward way.

The lamps of the well-known classical form, of which the Romans have left us numerous examples in bronze and *terra cotta*, survive in many of our modern underground workings, but especially in the metal mines of the Continent. In the collieries more generally their form has been changed to one with a globular, cylindrical, or conical oil-holder, and with a much smaller wick than would be used in the Roman lamp. The Scotch and some of the Saxons employ a little metal oil-lamp, with a hook on one side, by which it may be attached to their cap when travelling in low places on hands and feet, or when climbing ladders. In pits about Mons, in Belgium, an oblate form is preferred, resting upon a strong iron spike, by which it may be fixed into wood, or into the coal itself, at the required point of work. Lamps of this kind may be constructed to give a very tolerable light with vegetable oils, at the cost of from three farthings to one penny for eight hours. Within the last two years, lamps for burning petroleum and paraffine oil have been proposed, and a splendid light has been obtained, but coupled, in the examples which I have tested, with a disagreeable odour very objectionable in narrow excavations.

Our English colliers (as also some of those in Saxony, &c.) have more commonly been lighted at their work by tallow candles, which, for ordinary work, are from twenty to twenty-five to the pound, but for fiery collieries, used to be so thin as to weigh thirty and even forty to the pound. The candle is either fixed in a holder, with a spike at the end, or is attached by soft clay to the place whence it best throws a light on the work; if it be used in a draught of air, a shield of wood is placed behind it to prevent its "swealing." Before the successful introduction of the safety-lamp, it was the regular practice to test the presence of fire-damp in the working stalls and in the wastes by the appearances of the flame of a candle; and skilful, steady-handed pitmen acquired such a readiness in thus trying the gas, that they would sometimes almost play with it when standing within a hair's-breadth of destruction. The slim candle is for this purpose neatly trimmed, and then held out, shaded by one hand, so that the top of the flame can be more clearly watched. On being advanced gradually upward in a place where fire-damp is lodged, the flame is seen to elongate, and to assume a blue colour, more or less pure, according to the nature of the gases present; sometimes, indeed, if the carburetted hydrogen be much mingled with carbonic acid, nitrogen, &c., the "cap" of the flame will exhibit a grey or brown tint; and such variations will be frequent in the mingled impurities of the "return" air-courses. As some varieties of fiery gas are "quick" in comparison with others, it needs a cool head and unswerving hand to lower the candle again with the requisite stillness, when once it had shown too dangerous a cap. It seldom happens that the candle is now used for this purpose, unless to test the presence of the enemy in places capable of storing only a small quantity.

Towards the end of the last century, when it was attempted more and more to work in places infested with fire-damp, various substitutes for the old method of lighting were tried. The reflection of the sun's rays from a mirror was capable of throwing a sufficient light forward for some little distance from the shaft for the accomplishment of certain work about the pit-eye, but was inadequate to penetrate far into the workings. A premium attached to those men who could work best in the dark, for driving some dangerous place into which no candle could be taken. The steel-mill was then invented by Spedding, of Whitehaven, and acquired a considerable popularity. In this instrument a disc, with periphery of steel, is made to rotate rapidly by means of cog-wheels and a handle, whilst a sharp flint is held against the steel edge, and a succession of sparks is given off, which yield a feeble irregular radiance. One person had to turn the mill, whilst another plied the pick; and yet, in spite of its costliness, its miserable glimmer of a light, and its having distinctly caused several explosions, no other means of illumination could be employed; and it made so many friends, that even in 1822 it is described by a pitman as "an excellent instrument to travel dead waste with, because, when in the hands of a judge, it discovers, by its various shades of light, where gas is, and where it is not." *

The occurrence of very serious explosions in the county of Durham in the year 1812, led to the establishment of a Society for the Prevention of Accidents in Coal Mines, at whose meetings in Sunderland, in 1813, Dr. Clanny, of Newcastle, exhibited his first lamp, intended to give light in an explosive atmosphere, and of which a description was published in the Philosophical Transactions. In October and November, 1815, his lamp was tried in a fiery pit, whilst that of Sir Humphrey Davy is stated to have been first tested in practice only on the 1st January, 1816. But although thus early in the field, Dr. Clanny afterwards judiciously modified his lamp by applying to a part of it the invention of Davy.

This great philosopher first visited some of the collieries in 1815, and, after an elaborate series of investigations, during that year and 1816, perfected the lamp which was to be so great a boon to the mining community. It would be out of place here to refer at length to the successive steps of the inquiry which established the fact, that flame cannot be passed, except under pressure, through a wire gauze containing six, seven, or eight hundred holes to the square inch, and that hence the explosive mixture might ignite inside a gauze cylinder without communicating the flame to the gas outside it. The standard which was fixed on as the safe limit was a gauze with 28 iron wires to the linear inch, or 784 apertures to the square inch. A lamp of 1½ inches to 1⅝ inches diameter was at once found to be safe in the most inflammable air of the pits, so long as atten-

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* "The Pitman's Infallible Guide." Newcastle: 1822.

tion was paid to the caution which he inculcated, that it must not be exposed to a rapid current, or allowed to become red-hot from the combustion of the gas within it. Mr. Buddle showed that it thus became unsafe if exposed to a current of more than 3 or 4 feet per second, and Dr. Pereira proved that flame could be passed through the gauze, if the lamp were subjected to a sudden jerk. It is hence manifest, that, as stated by Davy himself, this is an instrument of perfect security only in careful hands, and that it should be guarded by a shield when exposed to a rapid current of explosive air.*

In the long series of years that have elapsed since the first safety lamps were sent down to the northern coalfields, a very small number of accidents has been traced to the lamp itself, and many of the alleged cases are doubtful. Its thorough efficacy has been daily tested, not only where it is employed for inspecting the working-places the first thing in the morning, or for travelling-places of known risk, but in many instances for the working of a large portion of, or even the entire area of a pit. And, indeed, it is like an effect of magic to pass, with the safety-lamp in hand, into a fiery stall or along the edge of a goaf, and to walk unscathed in the midst of an explosive compound, whose deadly power would dash you to pieces if there were but a wire awry in the gauze. Abundance of warning is given by it; and as the quantity of gas increases, the flame, at first elongated by a blue cap, flashes into an explosion within the lamp, more or less fierce according to the mixed nature of the air. When the carburetted hydrogen is mixed with common air in the ratios of from

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* Attention has of late been re-directed to this source of risk, and several modified lamps have been brought forward in consequence.

1 to 4 parts, to 1 to 12 parts, it is highly explosive; whilst below and above that proportion it burns quietly. But if the fire-damp burn in it until the gauze becomes red-hot, it is time to withdraw the lamp steadily from the place, or to extinguish it either by dipping it gently into water, or by drawing down the wick with the trimming wire.

The chief objection to the Davy lamp consists in its small amount of light, which leads the colliers, who are paid by the quantity of coal which they cut, to substitute, when they imagine they are safe, the open light of a candle, or of the lamp, with the gauze removed. So many serious accidents have arisen from this cause, that a vast number of modifications of the original lamp have been brought forward, some for the purpose of obtaining a fuller light, others with the object of so locking the gauze to the lamp, that the colliers shall be unable to take them asunder, or shall only do so with the certainty of putting out their light, or of being detected.

It would occupy too much space to describe the various contrivances which have been proposed for these purposes, but it is essential to notice a few of the safety-lamps which have come into extensive use.

1. The ordinary Davy-lamp, as most commonly employed in this country, A, Fig 38. The cylinder of iron wire gauze is fixed to a brass ring, which screws on to the oil-vessel. Its upper portion is double, in order to guard against the effect of the heated gases passing off from the combustion. It is guarded externally by three strong wires, or rods, attached at the top to a metal roof, above which the loop is placed for carrying or suspending the lamp. A thin wire, for trimming t wick, passes up through a close-fitting tube fror

bottom of the oil-vessel. It is commonly locked by a bolt, turned by a simple key, till its head is sunk even with, or below, the surface of the metal where it is inserted. A part of the circumference is sometimes protected by a curved shade of tin or horn, made to slide upon the protecting bars. The usual cost is 6*s.* 6*d.* to 7*s.* 6*d.*, and the weight about 1 lb. 6 ozs.

2. Clanny's lamp. The lower part of the gauze is replaced by a cylinder of thick glass, well protected by vertical bars. The feed air has to enter the lamp through the gauze above the glass; hence, what with the imperfect combustion, and the thickness of the glass, the light given off is not much greater than that of the common Davy, whilst the weight is double; and the risk alleged to attend the use of the glass, has added to the objections made to its common employment.

3. Lamp by Dubrulle, of Lille. This is a Davy, provided with a locking-bolt, so connected with an arm which lays hold of the wick, that if the oil-vessel be unscrewed from the gauze cylinder, the effect is to draw down the wick and extinguish the light. This and other analogous contrivances would be efficacious if the men could be prevented from taking with them lucifer matches; but as long as it is in their power to strike a light at will, the only real detection which has been applied seems to be a Belgian method of locking with a pin of lead, which, when put in its place by the lamp trimmer, has a device punched upon it. The lamp cannot then be opened without breaking the pin.

4. Stephenson's lamp, B, Fig. 38. The "Geordie," as it is called after its inventor, George Stephenson the engineer, is made of rather larger diameter than the Davy, but has the additional safeguard of a glass cylinder,

surmounted by a cap of perforated copper within the wire gauze. The feed air enters by a series of small orifices below the cylinders; and, in order that the light may burn well, it is important to hold the lamp, or suspend it, when at work, in a perpendicular position,

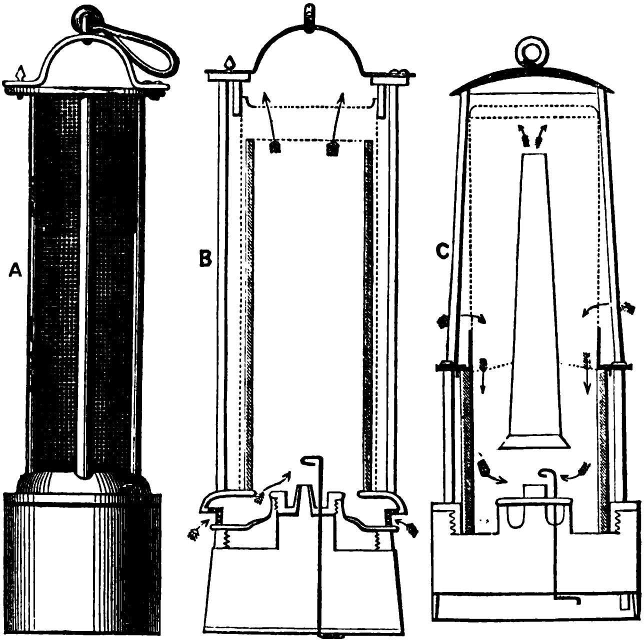

Fig. 38. Safety lamps. Scale, one-third true size.
A, Davy's, in elevation. B, Stephenson's, in section. C, Mueseler's.
In the sections the dotted lines are wire-gauze, the parts shaded with oblique lines are glass, the strong black lines sheet metal. The arrows represent the direction of the air-currents.

and to guard against these small feed-holes being clogged with oil and coal-dust. The glass is a preservative to the wire-gauze, and even should it be broken, leaves the lamp still safe. It is moreover free from the risk of overheating, since. when the air becomes highly explosive, the light goes out. A good many of these lamps are employed in certain British collieries, and when carefully treated and watched, give good results,

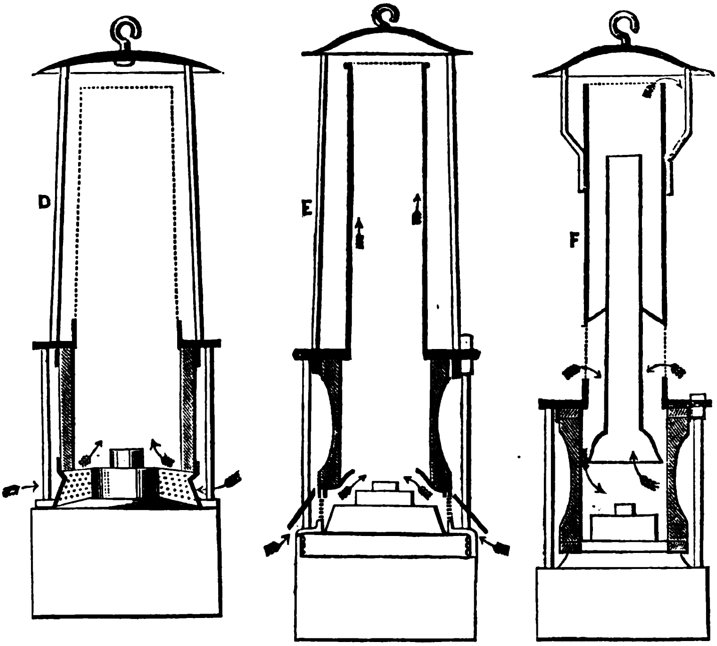

Fig. 39. Safety lamps. Scale, one-third true size.

D, Boty's. E, Eloin's. F, Eloin's Mueseler.

The dotted lines are wire-gauze, the parts shaded with oblique lines are glass, the strong black lines sheet metal.

which compensate for the extra weight and cost as compared with the Davy.

5. Boty's lamp, D, Fig. 39. A royal commission, appointed in Belgium to take into consideration the means of lighting fiery collieries, recommended, in addition to the simple Davy, this and the three following. In Boty's a good light is given through a short glass cylinder,

surmounted by a wire-gauze chimney, the feed air being admitted through a series of minute perforations a little below the level of the flame. The same precautions must be taken with regard to these minute orifices, as in the Stephenson. I have seen these lamps in use near Charleroi, where the agents expressed themselves well satisfied of their security, if the cylinder be made of properly annealed glass.

6. Mueseler's lamp, c, Fig. 38. This consists also of a glass cylinder below, and wire-gauze above; but, by the insertion of a central metal chimney opening a short distance above the flame, so strong an upward draught is produced by the heated gases, that the feed air is drawn briskly down from the wire gauze, and passes by the inside of the glass to the wick, thus keeping the glass cool, and insuring a superior combustion. Upwards of 20,000 of these lamps are said to be in daily use in Belgium, and I am assured by M. De Vaux, engineer-in-chief, that no accident has been traceable to their failure, although they have now been introduced for many years. The glass is of course subject to fracture, and its average life is eighteen months. The full light which they give, removing, as it does, the temptation of opening the safety lamps, is a strong point in their favour; and they have been employed with success by Mr. Lancaster, at collieries in Lancashire, and by Mr. Tylden Wright, at Shireoaks in Nottinghamshire. At the latter colliery, where they have been introduced for nearly five years, and are charged 5*s.* 3*d.* each, I learn that for six months 383 Mueselers had been in daily use, and consumed 1 gallon of refined rape each. In that period 69 glasses had been broken. A great convenience is, their not being affected by an amount

of draught sufficiently strong to blow out the common Davy; and some viewers hold it to be an advantage, whilst others object, that it goes out when the air becomes highly explosive.

7. Eloin's lamp, E, Fig. 39. This arrangement, proposed by M. Eloin, of Namur, about 1850, admits the air through a ring of wire gauze under an argand cap, surrounding the wick. Above this, the light is given off through a glass cylinder, formed in such a curve externally as to diffuse the rays. The upper part of the lamp surmounting the glass is a brass tube, covered at the top with wire gauze. A brass reflector slides up and down the protector bars, serving both to throw the light downward when needed, and to guard the glass against dropping water. An admirable light is given by the Eloin, but it requires to be carried in careful hands, since it is very apt, in rapid movement, to be suddenly extinguished.

8. Mueseler's lamp, modified by Eloin, F, Fig. 39. The combination of the principles of the two above lamps is clearly seen in the section.

The comparison of the various safety-lamps has acquired a new significance during the last few years. A number of systematic experiments have been carried out at various places in Great Britain, and also on the Continent, to determine the limits of danger when the lamp meets a current of air at too high a rate of velocity. Already Davy and Buddle had pointed out this source of risk, but the question had been allowed to slumber; and now, when it was announced by careful experimenters that the Davy would pass the flame if it were moved with a speed of 8 feet a second, and that all the other lamps hitherto thought safe could not endure a greater velocity than from 8 feet to 12 feet per second, it seemed alarming that no sufficient protection could be relied on in circumstances that must often occur. A rapid current of air in some part of the returns, a person walking hastily against the wind, a fall of the roof, a blower of gas, or even the stumble or jerk of a careless person might ignite the gas and cause explosion. Hence more than ever it seemed needful to take precautions, and at once to attack the problem of rendering the lamp more secure.

A host of new lamps have been brought forward, of which several have withstood successfully the ordeal of high velocity. Among these are Morison's, with two concentric glasses, between which the current of air has to find its way to the wick; Williamson's, also with double glasses, and feed air entering from below, as in the Stephenson; Bainbridge's, also fed from below; Hann's and others, in which the typical Davy, Clanny, and Stephenson have been modified, with extra safeguards to check the passing of the flame. Some of these, in which glass forms a large part of the construction, give a very good light; others are not approved because the checking of the air current prevents their burning briskly. Some inventors have addressed themselves to the greater security of the lock, as in the ingenious device patented by Craig and Bidder, for the lamp which can only be opened when placed over the poles of a powerful magnet. Others have, for economy's sake as well as for a good clear light, employed mineral oils, introducing them under the misleading name of Colzaline, as in Teale's "Protector," a lamp now in extensive use, and of which the general form is a modification of the older types, especially of the Mueseler, giving in some respects excellent results.

Meanwhile, the Belgian Government has repeatedly given consideration to the subject, and the King, in June, 1876, issued a decree, in which the Mueseler lamp alone is permitted to be used in fiery collieries. The employment of mineral oils is interdicted; and only three modifications of the typical lamp are to be allowed. This important document is completed by a series of full-sized figures of the several lamps which are thus sanctioned by authority.

Experiments on various lamps are recorded in the *Ann. des Travaux publiques*, tom. 31, and in the "Trans. No. Inst., 1868."

It is worthy of notice that whilst at present a great diversity of opinion obtains among our British colliery managers as to which is the best safety lamp, a very large majority adhere to the Davy as being the most sensitive lamp by which to test the presence of fire-damp.

To detect this gas when in minute quantity, Prof. Forbes renders it observable by the instrumentality of the sound given by a tuning-fork,* and E. H. Liveing has exhibited to the Engineers at Newcastle a beautiful little apparatus, in which the comparative illumination of a screen by a coil of platinum wire acted on by a magneto-electric machine will indicate ½ or even ¼ per cent. of gas.

With regard to the employment of safety lamps, there can be but one opinion of their value in testing the condition of the working-places before the men are admitted to them of a morning, and in the examination of those parts of a colliery not visited by the ordinary collier, where fire-damp may be expected to be present.†

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* British Association, Dublin, 1878.

† Though it is not yet used in practice, I would mention the "fire-damp indicator" of Mr. Ansell, of the Royal Mint, in which the *diffusion* of gases is made to indicate gas by an index hand on a dial.

But, as respects their introduction throughout the workings of a pit, the question is somewhat complex. It is apt to be the case, that if one precautionary measure be fully installed, another is neglected,—that when safety lamps are adopted for the entire operations of a mine, the ventilation is no longer a subject of the same attention; and unless there exist good local reason for it, it is obvious that the protection by wire gauze against present fire-damp is a less desirable kind of security than that of drowning the enemy in a full ventilating current, and sweeping him bodily away. Where the gas, however, is not merely given off continuously from the surfaces of freshly-cut coal, but bursts out from time to time in sudden blowers, the general use of safety lamps is imperative; and on such occasions, when for a short time the best ventilated workings may be "fouled," or rendered explosive, the lives of all in the pit will depend on the proper condition of the lamps, and on the obedience to discipline of those men who are interposed between the point of outburst and the exit to the surface. Similarly, in the working of pillars, where, with the movement of the ground, fire-damp may exude either from the roof or floor, or may be forced by a fall from the magazine in which it has been collecting, safety lamps are indispensable. It commonly occurs, that although such may be the case in portions of a colliery, other parts, and especially the ordinary narrow work in whole coal, may be safely conducted with open lights. Here it will be necessary to fix on certain limits within which safety lamps alone are to be employed, and to make it a stringent rule that no naked light be allowed to pass beyond a definite point in the roads. In Fig. 19, the bords, on the north, are worked with candles, the pillars, adjoining the goaf, with safety lamps; a special door is fixed upon as the place, beyond which no open light is allowed to be carried; and the course of the ventilating current, led backward and forward three times, as seen by the arrows in the figure, is so contrived as to guard against any communication of gas from the dangerous portions to the bords.

In no department of mining is a strict discipline and attention to orders so momentous as in this,—the question of lighting. The misplaced confidence, which is the result either of ignorance, of hardihood, or of long impunity, has led to the sacrifice of thousands of colliers, the innocent often suffering with the guilty; and among the most useful of the innovations of the governmental inspection is, that of giving authority to the code of rules to be established for every pit, and thus of protecting the majority of the men, the steadier workers, against the few reckless ones, who, choosing to act for themselves, steal in secret the luxury of their pipe, or some extra light, at the risk of their own and their comrades' lives.

CHAPTER XVII.

VENTILATION.

It needs no argument to impress on those who know the necessity of ventilating our public and private rooms, that it is in a high degree essential to take thought for the replacement of vitiated by fresh air in the low and often-complicated chambers of coal mines, where many men and horses are engaged in hard work, and where numerous lights, with gunpowder smoke and dust, aid in contaminating the atmosphere. But, in the workings of a colliery, additional causes come into play; a slow, yet constant change takes place in the surface of the substances exposed to the air, and the general result is, the absorption of oxygen; a large amount of watery vapour requires removal; the poisonous gas, carbonic acid, is frequently given off; and, more commonly, the insidious fire-damp, or carburetted hydrogen, exudes from the surfaces of the bared coal, or sometimes bursts from it in violent jets. The amount of air required for the health and safety of the men will therefore vary much in different localities, according to these unequal conditions; and whilst, in some cases, the slightest movement of air may suffice to keep a small colliery salubrious, in fiery coals worked over a large area an actual whirlwind must be forced through the principal passages in order to sweep away the noxious exhalations.

Notwithstanding the undoubted phenomena of the diffusion of gases, their intermingling in the chambers and drifts of mines is only partial, and the specific gravity of the gaseous bodies is practically a very important guide in testing their presence, and enabling them to be dealt with. Thus, carbonic acid (CO_2), with a specific gravity, as compared with air of 1·524, tends to occupy the deeper parts of excavations, and renders it unsafe, when they have been disused, to enter them without precaution. Sulphuretted hydrogen (HS) here and there evolved continuously, very poisonous, but readily detected by its offensive smell, is also slightly heavier than air; carbonic oxide (CO), most deadly, but occurring rarely from natural causes, is 0·970. Fire-damp, or light carburetted hydrogen (CH_4), the *grisou* of the French miners, has a specific gravity of 0·555, and is therefore commonly found to float along the upper portion of levels, to escape of itself from workings carried downhill, and to lodge in hollows or the higher parts of excavations. If mingled with air in the proportion of $\frac{1}{30}$th to $\frac{1}{15}$th, it may be detected by the "cap" on the flame of a candle or lamp. If in larger proportions, it becomes explosive, and is most violent when it forms $\frac{1}{8}$th or $\frac{1}{9}$th of the mixture. The presence of carbonic acid greatly reduces the explosive property. When there is as much as $\frac{1}{4}$th of the gas, it burns without explosion, and a still larger proportion causes suffocation. In fiery seams it may be observed exuding from the freshly-broken surfaces with a hissing sound; and if in large quantity, as with "blowers," or sometimes near faults, with a rushing noise, like the steam from a high-pressure boiler. Under these last circumstances it will rise through a column many yards high of water, and numerous accidents have occurred through a forgetfulness of this property. Some of these blowers will be exhausted in a few minutes, others will last for years,—like that at Wallsend, which gave off 120 feet of gas per minute—and may be then piped off and burned at the pit bottom. The evolution of the gases from the coal is greatly affected by the pressure of the atmosphere, a notably larger amount being emitted when the barometer is low; and hence that instrument becomes a useful adjunct in judging of the amount of ventilation needed at different times.

For the due ventilation of a colliery, it is therefore not sufficient to supply air enough for the breathing of men and horses and the burning of lights; but we must provide for the sweeping away of the products of breathing and combustion, for the removal of the gaseous results of blasting and of the decomposition of vegetable and animal matter; for the cooling of the excavations where the temperature is high partly from depth and partly from chemical change; and, lastly, for the dilution of the gases exuding from the coal.

In round numbers, 100 cubic feet of air per minute may be required for the health and comfort of each person underground, or for 100 men 10,000 cubic feet; but if fire-damp be given off—say at the rate of 200 cubic feet per minute—we should need at the very least thirty times that amount of fresh air to dilute it, or 6,000 cubic feet in addition. Increase the number of men and liability to gas, and 40,000 or 60,000 cubic feet of air may be indispensable for safety. Hence, we may point out once for all that no system of pipes can ventilate a mine, and that the large volumes of air required must be introduced through the drifts or workings themselves.

The subject now divides itself into two parts—first, the production of a current or "draught;" secondly, the distribution through the workings of the current so produced.

A spontaneous ventilation is produced by natural causes, which may always greatly assist, and, in some cases, may be sufficient for all purposes. To account for this on the simplest principles, let us observe what happens in summer and in winter with a diagrammatic working connecting two shafts of different depths.

The temperature of the rock is found, as we descend, to increase 1° Fahr. for about 60 feet of depth. Hence the air in workings of moderate depth will be in summer cooler, and in winter warmer, than the air at the surface. And as air expands in warming—and we know by Mariotte's law that the pressures of the gases are in an inverse ratio to their volumes—the colder column will press upon and displace the warmer. If, then, we compare the two cases, we shall find that in summer (Fig. 40) the deep shaft A C compared with a column, B E, of equal height in and above the shallower shaft will be the cooler and heavier of the two, and will establish a current in the direction of the arrows. In winter the effect will be reversed, and the warmer air will be expelled from the top of the deeper shaft.

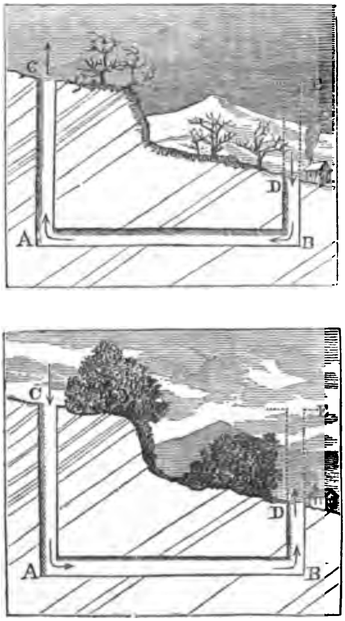

Fig. 40.

But at certain seasons—and especially if the shafts are not very different in depth—there will be equilibrium between the two, or, in other words, the ventilation will be checked or cease.

Under these circumstances we may artificially increase the difference of temperature—which is in fact the measure of the ventilating power—either by building a tower to lengthen the column of one of the shafts, or by lighting a fire in it for the purpose of expanding and lightening the air.

In early days it was usual to build a stack over the pit, and to attach to it a furnace accessible at the surface through doors; and in small pits, either this mode, or that of suspending a fire-lamp in the shaft, may perform useful service; but if a really large volume of air be required, we must heat the full height of the column in the upcast shaft, and by good brick lining, and prevention of the dropping of water, obtain a maximum effect in the greatest possible difference of temperature between the upcast and downcast shafts. Under favourable circumstances, spontaneous ventilation may be made to pass many thousands of cubic feet of air per minute through a colliery; but where the pits are deep and in good order, the quantity may be enormously increased by the application of a furnace at the bottom, or, if it be needed, by two, or even three, ventilating fires playing into the same shaft. For this purpose a furnace is usually placed in the plane of the seam, from 5 to 10 feet in width, and with fire-bars about 6 feet in length; the arch is built in fire-brick, and well isolated from the coal, the height above the bars being 3 to 5 feet, and below them 3 to 4 feet.

From the furnace to the shaft a gently-inclined passage—the *furnace drift*—leads the flame and heated air upwards; whilst if the return air be apt to be *foul*, it may be led through a higher passage—the *dumb drift*—into the shaft at such a height above the mouth of the furnace drift as to secure the gas from firing, and the furnace will then be fed either with a safe portion of the returns, or with a "scale" (a small current) of fresh air from the downcast shaft. For perfect combustion, the coal should be thrown on frequently, and should form a thin fire; and thus an average temperature of 140° to 160° Fahr. may be obtained in the upcast shaft, which, if we take an average of 60° in the downcast, will give a difference of 60° or 80° Fahr., on which the ventilating power may be calculated.

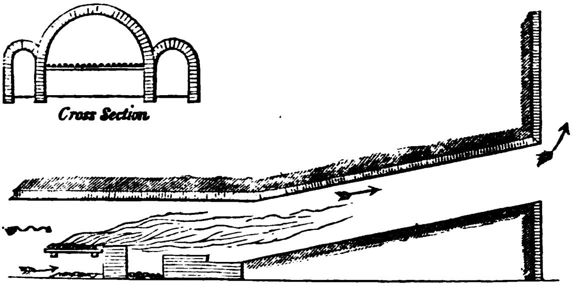

Fig. 41. Ventilating furnace, in longitudinal and cross section. Scale, ½-inch to 1 foot.

The quantity of small coal consumed in such furnaces varies from 2 to 5 tons per twenty-four hours; and the volume of air passed—which may be from 15,000 to 150,000 cubic feet per minute—depends in a great measure on the diminution of the resistance offered by friction in the workings.

In order to obviate some of the short-comings of the common furnace, such as the difficulty of increasing its power when circumstances demand it, and the interruption of its work caused by cleaning, new furnaces have been erected at Hetton, at the suggestion of Mr. John Daglish, which are 26 feet in length, so as to allow either the shifting of the place of the fire, or its increase; whilst by a series of doors, the admission of

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* V. paper by Mr. Daglish. Trans. North. Inst. Min. Eng. Vol. ix.

the air may be regulated according to conditions, either above or below the fire-bars. The enormous volumes of air actually circulated by these means, and the facility and certainty of its action, have obtained for the furnace a decided preference in all our deep British pits.

A vast number of mechanical contrivances have been employed in mines sometimes for forcing in air, but more commonly for drawing it out from the workings, and thus establishing a constant current. It would need a volume fairly to describe them, and we can here only glance at a few of those which have been most largely applied in practice.

The WATERFALL, formed by turning a special stream into the downcast shaft, or by allowing the pump-cisterns to run over, is a useful auxiliary, especially for driving in air after an accident.

The AIR-PUMP—employed at a very early period in the mines of the Hartz—has been, on a magnified scale, adopted at many collieries, especially in Belgium. It has generally had pistons working in cylinders of from 6 to 10 feet in diameter, placed sometimes vertically, sometimes horizontally. The valves have had to be complicated from being very numerous, and from being fitted with counterbalances, attached by light levers, in order to diminish the resistance. A great diminution in friction has been obtained by making the piston in the form of a gasometer, plunging with its sides in a ring of water. This latter plan has been carried out on the largest scale in Mr. Struvé's ventilator, now working at many collieries in South Wales. His piston is a close-topped wrought-iron bell, of 12 to 22 feet in diameter, working up and down in water; and by means of ranges of valves above it and below, placed in the walls of the piston-chamber—drawing in, and forcing out, air at each up and each down stroke. The action will readily be seen from the adjoining figure, in which the piston is making its down stroke. These machines are usually composed of two such pumps, worked by a steam-engine, and are capable of giving a theoretical amount

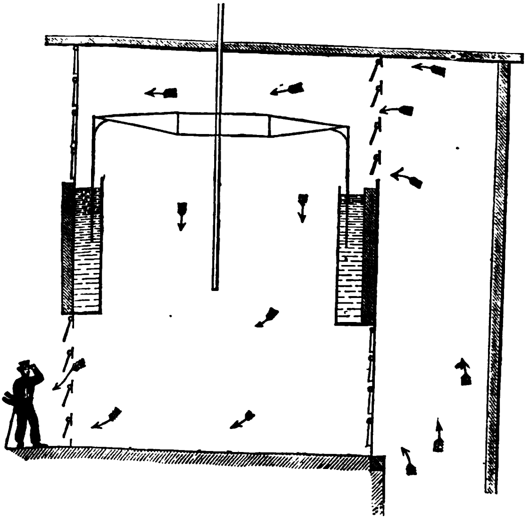

Fig. 42. Struvé's ventilator. Scale, ¼-inch to 10 feet.

of 20,000 to 100,000 cubic feet of air per minute. Their cost is about £200 per calculated 10,000 cubic feet. Horizontally-working pistons in prismatic chambers were erected in 1828 by M. Brisco, near Charleroi, and on a larger scale by M. Mahaux in 1861. One applied to the colliery of Monceau Fontaine, by Scohy, in 1861, was capable of extracting 45,000 cubic feet per minute. These are all greatly exceeded by Nixon's ventilator, now working at the Navigation Pit, near Aberdare. Its sheet-iron pistons—30 feet by 22 feet, or no less than 660 feet area each—are supported on wheels traversing on rails a stroke of 7 feet. The chambers are fitted, as in Struvé's machine, with flap valves 16 inches by 24 inches, and 672 in number. At nine strokes per minute, the theoretical quantity of air expelled would be 166,000 cubic feet per minute; but a large reduction has to be allowed for leakage.

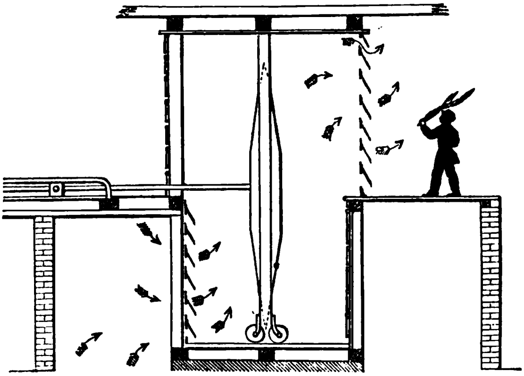

Fig. 43. Nixon's ventilator, Aberdare. Scale, ⅛-inch to 10 feet.

Fans.—These instruments, with straight radial vanes, were abundantly used in the German mines in Agricola's time, about 1550. Similar machines on a larger scale, 8 to 22 feet in diameter, vertical or horizontal, have been applied at several collieries; but from their leakage, and the considerable velocity needed, have not given very good results.

M. Guibal, of Belgium, commencing about the year 1860, devised and erected several examples of an improved fan of from 20 to 28 feet in diameter, and 6 to 10 feet wide. The figure shows its form and the great improvement of casing it in, and providing a slide valve to a part of the casing to meet the varying conditions of a mine. The stack, expanding outwards, is stated to counteract to a great extent the loss due to the high velocity given to the air by the vanes; and experiments made on the machines erected at Bully-Grenay, near Béthune, and Montceau-Fontaine, near Charleroi, have shown a useful effect of 30 to 50 per cent. from the steam in the cylinder, and 60 to 70 per cent. of the force transmitted to the axle.*

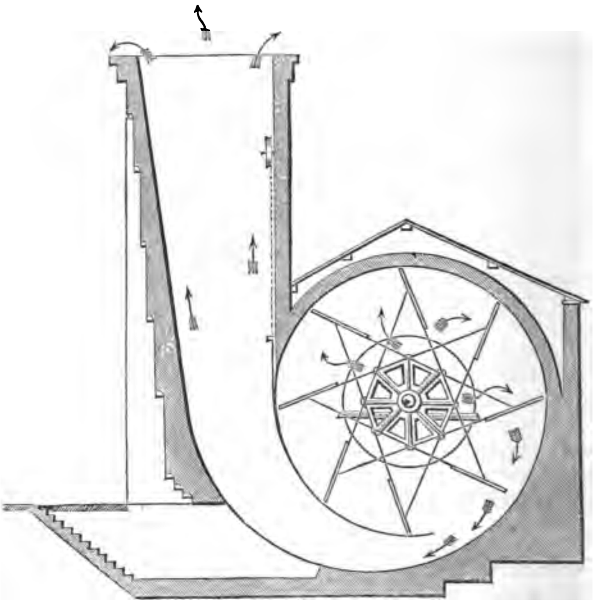

Fig. 44. Guibal's fan. Scale, 1 inch to 20 feet.

M. Lemielle has devised a very ingenious ventilator, now at work in many Belgian and French pits, and at Ashton Vale, near Bristol, where it has acted satisfactorily for above ten years with very little necessity for repairs. Within a large cylinder of brick, wood, or sheet-iron, a smaller drum is placed excentrically, and made to revolve. On the surface of this drum are two or more valves or shutters, which, by means of iron rods moving freely round an elbowed axis in the centre of the large cylinder, lie close to the drum in one part of the revolution, and open out in another. The section shows by the arrows how the air will thus be expelled by the shutters as they approach the point of outlet.*

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* Between 1863 and 1880 upwards of 200 of these fans, some up to 40 and 50 ft. diameter, have been put to work in the north.

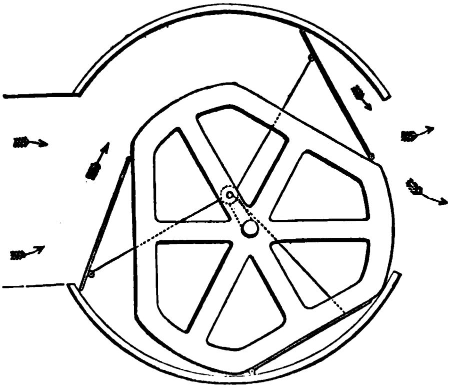

Fig. 45. Lemielle's ventilator.

Fabry's machine is another—on the fan principle—much approved on the Continent. Two axes, each fitted with three very broad blades (6 to 10 feet), revolve in opposite directions, and each blade is formed with a cross arm, so curved as to give close contact during revolution, and thus prevent communication from within to the external air. Above half of the circumference of these fans fits closely within a casing of brick or wood, and the foul air, when the machine is employed for exhaustion, is taken by the blades on approaching the lower part of their circle of revolution, is carried on each side outward, and ejected on passing the upper limit of the curved casing. The moderate velocity at which it may be driven, and its durability, have obtained this machine a good name.

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* The last few years have been fruitful in the erection of some large Lemielles in this country, and of sundry other machines on the centrifugal principle, as those of Waddle, Lambert, &c., and the successful ventilators of Schiele and Cooke.

Little more than a dozen years have elapsed since a vigorous attempt was made, under the impulse of a most injudicious parliamentary committee, to substitute for the furnace the mechanical action of steam jets. The subject was elaborately tested in practice by Messrs. T. E. Forster, Nicholas Wood, and others, and it was clearly shown that high-pressure steam, generated either at surface or underground, and allowed to escape from a series of small jets—say thirty to forty in number, and from $\frac{1}{16}$th to $\frac{1}{8}$th of an inch in diameter—was capable of doing good service, especially as an auxiliary at times of accident; but was utterly unable to compete in economy with the furnace.

In selecting our ventilating power, it must be remembered that the great object is to obtain a large volume of air at moderate velocity, and that on this account most of the simple fans, and certain other classes of machine which have to force the air through insufficient valve room, give it an unnecessary velocity, which, in other words, means increased resistance, or diminished ventilation.

Furthermore, that whilst the furnace exerts its fullest advantages in deep and dry upcasts, to which the air travels through roomy windways, the mechanical ventilators may be most properly applied at pits where these conditions are reversed.

Let us now consider the distribution of the air through the workings, remembering that without due attention to its details we may have a storm of ventilating wind in the shafts, and yet a deadly stagnation in the interior; or one portion of the pit safe and wholesome, another foul, and verging on explosion.

First of all, the means of carrying the air current up to or near the place where the men are employed, consists in cutting a drift or windway across from one working spot to another, and as we advance, closing the old openings by doors, or *stoppings*, so as to force the air through the required passage only. To take a simple case: Fig. 46 represents a pair of levels driven a short way out from a shaft divided by brattice into D and U, the downcast and upcast portions. The pillar between the levels is holed through by a "thirl" at A, when the drift-ends are advanced but little beyond that point. Subsequently, when B has been thirled, a *stopping* is put into A either by brick and mortar, or stowed rubbish, or both; and similarly when C has been opened, B will be closed. If, however, a thoroughfare for the men be required, so that a stopping is inadmissible, a door, or—where the ventilation is important—two doors, or even three, are put up, so far apart that a

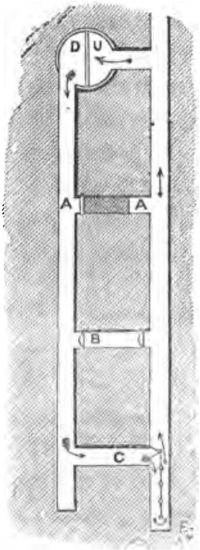

Fig. 46.
Scale 1 inch to 80 feet

horse and trams can pass the one and have it closed after them before the second is opened. Thus, loss of air is avoided, and the tendency of the current to take the shortest way to the upcast is checked. Indeed, a watchful eye must always be kept on the *intake* current D C, which constantly presses upon the barriers which divide it from the *return* E U, and leaks through all available openings, to the diminution of the ventilation in the inner workings. Doors and stoppages, therefore, require constant attention, or by a trifling leakage at each of them, a ventilating current powerful enough at the beginning of its run, may lose all its force ere it reaches at half a mile or a mile or two distance, the locality where it is really needed. If, meanwhile, the coal should be so fiery as to render it dangerous to proceed above four or five yards without extra precaution, *bratticing* is employed as a temporary measure until the next thirl is holed. Thus, supposing in the Fig. 46 the end E alone is dangerous, a range of upright posts is erected between roof and floor, from the side of the pillar B C to within a short distance of the face at E, and brattice boards are nailed to them, dividing the level into two parts, and making the current travel as represented by the arrows.* A light door is generally added for the passage of the men or horses and trams. These features are shown in the section of the working of a 7-foot seam, Fig. 47, where the air passes up close to the man on the left, and then turns behind the brattice.

A single current may thus be carried to the various working places, and brought back to the same or to another shaft; whilst if the power be great, the airways roomy, and the doors and stoppings in good order, it will be maintained for a length of several miles without serious loss. If the form of the works be such as that shown in Fig. 21, as a variety of "long-wall," a stream of air starting each way from the downcast shaft will simply and effectually ventilate the mine. But the same method, generally applied as it used to be, years ago, to more complicated workings, is highly objectionable: it would leave the mass of the openings inside of the working "bords" *dead* or stagnant; it would needlessly carry fire-damp from dangerous to otherwise safe places, and the body of air which in the morning went down into the pit fresh and pure would take till night to drag itself along some twenty or thirty miles of drift, and would visit all its later scenes of work overheated, clogged with dust and smoke, and laden with impurities.

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* For temporary purposes a useful brattice-*cloth* is largely manufactured by Mr. Darcy Lever, of Bolton.

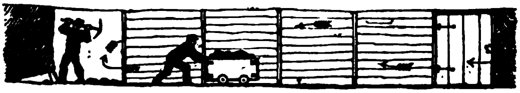

Fig. 47.

Spedding, about 1760, introduced the *coursing of the air* by twos or threes through the whole of the opened passages, and soon afterwards all the chief northern viewers recognised the importance of shortening the runs, and obtaining larger volumes. For this it would be needful either to have more shafts, and work, as it were, several separate mines, or—what is more suitable when the shafts are ample enough—to *split the air*. This latter plan, by which a number of separate currents are obtained, is perhaps the greatest improvement effected in the airing of pits, and when combined with the division of the area into panels or districts, has the advantage of confining danger, or the results of accident, within narrow limits. Take the case of a colliery having 12-feet shafts, and air-ways of 4 feet by 5 feet, or 20 feet area; the shaft having 113 feet area will be fully adequate to pass the air required, not for one or two such air-ways, but for at least five. Each may then ventilate a different district, and they may be brought together again either at the upcast shaft, or into certain roomy return air-ways approaching it. As we increase the area or number or power of the shafts, so the number of the splits may be increased, and since the resistance varies directly with the length of the road which the air current has to travel, and inversely as the sectional area of the passage, it is manifest that if the runs are shortened, and the air-ways increased in size, the same ventilating power will pass a larger volume of air. Reference to Fig. 19 will show this arrangement in a portion of the working of a large colliery. But the balancing of these splits requires nice management, or the air would tend to desert the longer for the shorter runs, and where inequalities in the length exist, it is necessary to put in regulators, which, checking the entry of the air into the shorter, may force it into the longer runs. It is upon such principles that some of the northern collieries succeed in passing through their workings the enormous volumes of from 150,000 to 300,000 cubic feet per minute.

When the workings assume this complicated form, the number of doors to be tended by trappers is nevertheless greatly diminished; but frequent *crossings* have to be made where one air-current is carried across the course of another (*see* Fig. 19, c). Thus, the "returns" are generally made to mount over the intake drifts, and are divided from them either by timber or brick arching, or boiler-plate (as at Kirkless Hall), or occasionally —for extra security—by being carried up to some height in the solid measures, so as, in the event of explosion, to prevent the risk of one passage being blown open into the other.

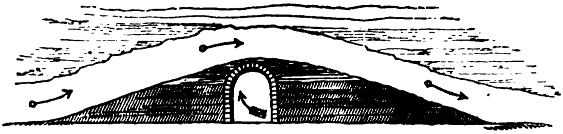

Fig. 48. Air-crossirg.

It is observable that in the more serious accidents from explosion a great majority of the sufferers lose their lives, not from the actual violence or fire of the blast, but from suffocation by the deadly after-damp consisting of the products of combustion. Most fearful is this when dependence has been placed on a bratticed shaft, the brattice is shattered, and the air passing down one portion and up the other, leaves the workings *dead* or without air, and the poor fellows who may have escaped the force of the actual explosion fall victims to suffocation. But independently of bratticed shafts, the same evil occurs in a modified form in every colliery, and due attention has very rarely been shown to so laying out the works, that in case of a blast sufficiently heavy to blow out the doors and shake down the lighter class of stoppings, there may still remain between the downcast and upcast shafts a sufficiently long course of unbroken air-current to afford a better chance of escape to the colliers, who can flee thus far from their working places. In Fig. 46 (p. 217), it may be seen how, if the stopping at A or the doors at B are blown out by explosion, the air would take that shorter course, and the inner workings be laid dead; and an examination of Fig. 19 will show the same result more forcibly. The further the two important shafts can be separated, the longer will be such independent air-course to which the men may escape. An upcast pit to the rise may often come in usefully in this way; but no general rule can be laid down, because a shaft so situate may often be so much shallower than the other as to form a less efficient furnace-shaft; and in cases of this kind—if the depth of the rise pit be too small for good ventilation by this means—it becomes a question whether a mechanical method would not be preferable.

The quantity of air which passes is measured by taking the sectional area of a drift, and multiplying it by the velocity in feet per minute, to obtain the number of cubic feet circulating in that time. The velocity is obtained either by observing the rate at which a puff of powder or tobacco smoke travels along a measured distance, or by an anemometer. The instrument most frequently used in collieries is that of Biram, made in various sizes, from 3 to 12 inches in diameter, by Davis, of Derby, which by wheel work and index hands registers the number of feet of air in tens, hundreds, and thousands, which have passed through it in a given time. M. Combes, and, more recently, Mr. Casella, and other makers, have devised for this purpose a smaller and more delicate instrument, depending for its results, like the former, on the revolution of a wheel fitted with light vanes.

In order to test the different densities of the currents on opposite sides of a brattice, a door, or stopping, a manometer or water-gauge is employed. This, although it gives no criterion of the amount of ventilation, is very useful for comparisons, as giving a measure of the resistances, or of what is technically called the *drag* of the mine, and distinctly pointing out any unusual obstruction such as may be caused by a fall of roof in the air-ways.

The above brief sketch, although not pretending to go into the details of exceptional circumstances, may, I trust, be sufficient in a general way to set forth the principles and practice upon which the ventilation of our larger collieries has been brought into so high a position of effectiveness by the skill and perseverance of the leading coal-viewers.

CHAPTER XVIII.

COLLIERY ACCIDENTS AND THEIR PREVENTION.

THE melancholy fact that from 900 to 1,200 persons are every year killed in our British coal mines, forcibly attracts attention to the inquiry, what proportion of these numerous accidents are due to preventible causes, and how far a part of them are inseparable from the dangerous nature of the collier's occupation. When a catastrophe of unusual magnitude occurs, public feeling is aroused, newspaper articles are written, and parliamentary inquiries are set on foot; but the majority of the accidents are little noticed, except in the immediate vicinity, and they take place at points so remote and so widely distributed, as to show that the main difficulty in dealing with them rests in the necessity of keeping up an unceasing watchfulness among many thousands of men, workmen as well as managers.

It has resulted chiefly from the excitement caused by the more destructive explosions, that several volumes have been published, filled with important evidence given before Committees of the Lords and Commons in 1835, 1848, 1852, and 1854. Furthermore, since the Mine Inspection Act in 1850, and the appointment of inspectors under the Home Office, now twelve in number, a vast amount of valuable information is afforded in their published reports, especially in the analysis of the chief accidents which have taken place in the year. By this means not only are principles and details of practice laid down and confirmed, but many of what may be termed accidents from unforeseen causes, are so set before us, that a diligent study of their descriptions ought year by year to diminish their occurrence. It is sometimes objected to the Government inspection that the number of casualties is not diminished; but it should be borne in mind that the quantity of coal annually extracted has been so largely on the increase that, if with a nearly doubled production, and of course with a much greater number of hands, the sum total of deaths has not increased, the results of the system cannot but be considered as successful.

The careful perusal of these documents is strongly recommended to all who are interested in colliery operations, and from their detailed explanations it will be seen that not a year passes without accidents arising from an infraction, wilful or accidental, of rules which have been laid down as being generally applicable.

The following are the General Rules to be observed under the Coal Mines Regulation Act of 1872 :—

(1.) An adequate amount of ventilation shall be constantly produced in every mine, to dilute and render harmless noxious gases to such an extent that the working places of the shafts, levels, stables, and workings of such mine, and the travelling roads to and from such working places, shall be in a fit state for working and passing therein.

(2.) In every mine in which inflammable gas has been found within the preceding twelve months, then once in every twenty-four hours if one shift of workmen is employed, and once in every twelve hours if two shifts are employed during any twenty-four hours, a competent person or competent persons, who shall be appointed for the purpose, shall, before the time for commencing work in any part of the mine, inspect with a safety lamp that part of the mine, and the roadways leading thereto, and shall make a true report of the condition thereof, so far as ventilation is concerned, and a workman shall not go to work in such part until the same and the roadways leading thereto are stated to be safe. Every such report shall be recorded without delay in a book which shall be kept at the mine for the purpose, and shall be signed by the person making the same.

(3.) In every mine in which inflammable gas has not been found within the preceding twelve months, then once in every twenty-four hours a competent person or competent persons, who shall be appointed for the purpose, shall, so far as is reasonably practicable immediately before time for commencing work in any part of the mine, inspect that part of the mine and the roadways leading thereto, and shall make a true report of the condition thereof so far as ventilation is concerned, and a workman shall not go to work in such part until the same and the roadways leading thereto are stated to be safe. Every report shall be recorded without delay in a book which shall be kept at the mine for the purpose, and shall be signed by the person making the same.

(4.) All entrances to any place not in actual course of working and extension shall be properly fenced across the whole width of such entrance, so as to prevent persons inadvertently entering the same.

(5.) A station or stations shall be appointed at the entrance to the mine, or to different parts of the mine, as the case may require, and a workman shall not pass beyond any such station until the mine or part of the mine beyond the same has been inspected and stated to be safe.

(6.) If at any time it is found by the person for the time being in charge of the mine or any part thereof that by reason of noxious gases prevailing in such mine or such part thereof, or, of any cause whatever, the mine or the said part is dangerous, every workman shall be withdrawn from the mine or such part thereof as is so found dangerous, and a competent person who shall be appointed for the purpose shall inspect the mine or such part thereof as is so found dangerous, and if the danger arises from inflammable gas shall inspect the same with a locked safety lamp, and in every case shall make a true report of the condition of such mine or part thereof, and a workman shall not, except in so far as is necessary for inquiring into the cause of danger or for the removal thereof, or for exploration, be readmitted into the mine, or such part thereof as was so found dangerous, until the same is stated by such report not to be dangerous. Every such report shall be recorded in a book which shall be kept at the mine for the purpose, and shall be signed by the person making the same.

(7.) In every working approaching any place where there is likely to be an accumulation of explosive gas, no lamp or light other than a locked safety lamp shall be allowed or used, and whenever safety lamps are required by the Act, or by the special rules made in pursuance of the Act to be used, a competent person who shall be appointed for the purpose shall examine every safety lamp immediately before it is taken into the workings for use, and ascertain it to be secure and securely locked, and in any part of a mine in which safety lamps are so required to be used, they shall not be used until they have been so examined and found secure and securely locked, and shall not without due authority be unlocked, and in the said part of a mine a person shall not, unless he is appointed for the purpose, have in his possession any key or contrivance for opening the lock of any such safety lamp, or any lucifer match or apparatus of any kind for striking a light.

(8.) Gunpowder or other explosive or inflammable substance shall only be used in the mine underground as follows:

(*a.*) It shall not be stored in the mine:

(*b.*) It shall not be taken into the mine, except in a case or canister containing not more than four pounds:

(*c.*) A workman shall not have in use at one time in any one place more than one of such cases or canisters:

(*d.*) In charging holes for blasting, an iron or steel pricker shall not be used, and a person shall not have in his possession in the mine underground any iron or steel pricker, and an iron or steel tamping rod or stemmer shall not be used for ramming either the wadding or the first part of the tamping or stemming on the powder:

(*e*.) A charge of powder which has missed fire shall not be unrammed:

(*f*.) It shall not be taken into or be in the possession of any person in any mine, except in cartridges, and shall not be used, except in accordance with the following regulations, during three months after any inflammable gas has been found in any such mine; namely,

(1.) A competent person who shall be appointed for the purpose shall, immediately before firing the shot, examine the place where it is to be used, and the places contiguous thereto, and shall not allow the shot to be fired unless he finds it safe to do so, and a shot shall not be fired except by or under the direction of a competent person who shall be appointed for the purpose:

(2.) If the said inflammable gas issued so freely that it showed a blue cap on the flame of the safety lamp, it shall only be used—

(*a*.) Either in those cases of stone drifts, stone work, and sinking of shafts, in which the ventilation is so managed that the return air from the place where the powder is used passes into the main return air course without passing any place in actual course of working; or

(*b*.) When the persons ordinarily employed in the mine are out of the mine or out of the part of the mine where it is used:

(*g*.) Where a mine is divided into separate panels in such manner that each panel has an independent intake and return airway from the main air course and the main return air course, the provisions of this rule with respect to gunpowder or other explosive inflammable substance shall apply to each such panel in like manner as if it were a separate mine.

(9.) Where a place is likely to contain a dangerous accumulation of water the working approaching such place shall not exceed eight feet in width, and there shall be constantly kept at a sufficient distance, not being less than five yards, in advance, at least one bore-hole near the centre of the working, and sufficient flank bore-holes on each side.

(10.) Every underground plane on which persons travel, which is self-acting or worked by an engine, windlass, or gin, shall be provided (if exceeding thirty yards in length) with some proper means of signalling between the stopping places and the ends of the plane, and shall be provided in every case, at intervals of not more than twenty yards, with sufficient man-holes for places of refuge.

(11.) Every road on which persons travel underground where the load is drawn by a horse or other animal shall be provided, at intervals of not more than fifty yards, with sufficient man-holes, or with a space for a place of refuge, which space shall be of sufficient length, and of at least three feet in width, between the waggons running on the tramroad and the side of such road.

(12.) Every man-hole and space for a place of refuge shall be constantly kept clear, and no person shall place anything in a man-hole or such space so as to prevent access thereto.

(13.) The top of every shaft which for the time being is out of use, or used only as an air shaft, shall be securely fenced.

(14.) The top and all entrances between the top and bottom of every working or pumping shaft shall be properly fenced, but this shall not be taken to forbid the temporary removal of the fence for the purpose of repairs or other operations, if proper precautions are used.

(15.) Where the natural strata are not safe, every working or pumping shaft shall be securely cased, lined, or otherwise made secure.

(16.) The roof and sides of every travelling road and working place shall be made secure, and a person shall not, unless appointed for the purpose of exploring or repairing, travel or work in any such travelling road or working place which is not so made secure.

(17.) Where there is a downcast and furnace shaft, and both such shafts are provided with apparatus in use for raising and lowering persons, every person employed in the mine shall, upon giving reasonable notice, have the option of using the downcast shaft.

(18.) In any mine which is usually entered by means of machinery, a competent person of such* age as prescribed by the Act shall be appointed for the purpose of working the machinery which is employed in lowering and raising persons therein, and shall attend for the said purpose during the whole time that any person is below ground in the mine.

(19.) Every working shaft used for the purpose of drawing minerals or for the lowering or raising of persons shall, if exceeding fifty yards in depth, and not exempted in writing by the inspector of the district, be provided with guides and some proper means of communicating distinct and definite signals from the bottom of the shaft and from every entrance for the time being in work between the surface and

* A male of not less than 18 years of age.

the bottom of the shaft to the surface, and from the surface to the bottom of the shaft and to every entrance for the time being in work between the surface and the bottom of the shaft.

(20.) A sufficient cover overhead shall be used when lowering or raising persons in every working shaft, except where it is worked by a windlass, or where the person is employed about the pump or some work of repair in the shaft, or where a written exemption is given by the inspector of the district.

(21.) A single linked chain shall not be used for lowering or raising persons in any working shaft or plane except for the short coupling chain attached to the cage or load.

(22.) There shall be on the drum of every machine used for lowering or raising persons such flanges or horns, and also if the drum is conical, such other appliances, as may be sufficient to prevent the rope from slipping.

(23.) There shall be attached to every machine worked by steam, water, or mechanical power, and used for lowering or raising persons, an adequate break, and also a proper indicator (in addition to any mark on the rope) which shows to the person who works the machine the position of the cage or load in the shaft.

(24.) Every fly-wheel and all exposed and dangerous parts of the machinery used in or about the mine shall be and be kept securely fenced.

(25.) Every steam boiler shall be provided with a proper steam gauge and water gauge, to show respectively the pressure of steam and the height of water in the boiler, and with a proper safety valve.

(26.) After dangerous gas has been found in any mine, a barometer and thermometer shall be placed above ground in a conspicuous position near the entrance to the mine.

(27.) No person shall wilfully damage, or without proper authority remove or render useless, any fence, fencing, casing, lining, guide, means of signalling, signal, cover, chain, flange, horn, break, indicator, steam gauge, water gauge, safety valve, or other appliance or thing provided in any mine in compliance with the Act.

(28.) Every person shall observe such directions with respect to working as may be given to him with a view to comply with the Act or the special rules.

(29.) A competent person or competent persons who shall be appointed for the purpose shall, once at least in every twenty-four hours, examine the state of the external parts of the machinery, and the state of the head gear, working places, levels, planes, ropes, chains, and other works of the mine which are in actual use, and once at least in every week shall examine the state of the shafts by which persons ascend or descend, and the guides or conductors therein, and shall make a true report of the result of such examination, and such report shall be recorded in a book to be kept at the mine for the purpose, and shall be signed by the person who made the same.

(30.) The persons employed in a mine may from time to time appoint two of their number to inspect the mine at their own cost, and the persons so appointed shall be allowed, once at least in every month, accompanied, if the owner, agent, or manager of the mine thinks fit, by himself or one or more officers of the mine, to go to every part of the mine, and to inspect the shafts, levels, planes, working places, return air-ways, ventilating apparatus, old workings, and machinery, and shall be afforded by the owner, agent, and manager, and all persons in the mine, every facility for the purpose of such inspection, and shall make a true report of the result of such inspection, and such report shall be recorded in a book to be kept at the mine for the purpose, and shall be signed by the persons who made the same.

The various districts are more or less subject to different kinds of accident according to local conditions, and the causes are shown in the table of deaths for 1878, increased this year by the Abercarn explosion.

Name of District.	Explosions.	Falls of roof and coal.	Deaths in shafts.	Miscellaneous, underground.	At surface.	Total.
1. Northumberland, Cumberland, and North Durham...	1	32	4	8	6	51
2. South Durham	4	37	7	25	10	83
3. North and East Lancashire	45	33	4	8	9	99
4. West Lancashire and North Wales	204	54	9	22	15	304
5. Yorkshire	4	39	5	22	10	80
6. Derbyshire, Notts, Leicestershire, Warwickshire ...	0	31	11	8	5	55
7. North Staffordshire, Cheshire, and Shropshire	28	21	10	8	0	62
8. South Staffordshire and Worcestershire	1	31	7	7	1	47
9. Monmouthshire, Gloucestershire, Somersetshire ...	268	45	4	13	3	333
10. South Wales	7	62	21	19	14	123
11. Eastern Scotland	2	33	17	6	7	65
12. West Scotland	22	25	5	8	4	64
Lives lost in coal-pits in 1878...	586	443	104	149	84	1,366
Total including ironstones	586	469	111	161	6	1,413
Total for 1877	345	448	129	187	99	1,208

Let us pass to a review of the more prolific sources of accident:—

1. *Falls of roof.*—These are occasioned especially in high seams, by the removal of the upper portions of the coal, more particularly when the whole thickness, as for the most part in South Staffordshire, is taken at one working. In other cases they arise from careless holing or undercutting, without due attention to sprags or props, or from the sudden detaching of bell-moulds, or lumps of ironstone, or masses of shale from the roof. In general these falls can only be guarded against by limiting the size of the excavations, and setting timber in sufficient quantity and in the most judicious manner. When the ordinary colliers are not practised or apt at this work, it is important that it should be carried out by duly qualified deputies. In some parts of the country an unfortunate system prevails of employing *butties*, or contractors, who, intent on getting the coal at a certain price, are prone to neglect the precautions which cost money, and which thus diminish their profits. In the long-wall workings, where the fall of the roof has for a stranger a most threatening appearance, nogs and pack-walls as well as single punch-props aid in giving the men security, but when the roof is treacherous, hourly caution needs to be exercised by the managers and supervisors; and whilst in some cases the premature removal of props may be dangerous, in others the omission to remove some of them will cause an irregular fracture often attended with serious results. Whatever the method of work, let there be no lack of prop-wood; and to prevent neglect caused by the colliers' grudging the time which would have to be

devoted to it, let such wood be cut for them in proper lengths, and carried near to their places of work. It is no less lamentable to note the great loss of life from supineness and blind confidence with respect to the roof, than it is wonderful to see what may be done, for a limited time, by a few well-set sticks of timber in the midst of crush and pressure that appear overwhelming.

2. *Explosions of fire-damp.* — According to the abundance of gas, the form of the excavations, and the efficiency of the ventilation, explosions may be either quite harmless, or may injure only one man or a few men in a single locality, or in the worse cases may flash forth with such lightning speed and fury as to leave not a man alive.

Certain coals, for example, are so fiery that when the air-current is brisk enough to render the experiment safe, you may with your candle, every now and then, set the gas alight on the freshly cut surface, and it will flash and flicker away for a few inches or feet in length. But woe betide the experimenter if there be any roof-cavity or unventilated corner near, in which a quantity of the explosive "damp" may have accumulated. If only there be plenty of air, such a bord or end may often be safely worked with candles, but the men should be provided with a wet cloth with which they may dash out the fire; and at the famous Wallsend pits small cannon have been used with advantage for extinguishing the flame by concussion, in case of its catching at the open lights and being more serious than ordinary. The safety-lamp is, however, now commonly used under such circumstances; and yet even with this safeguard, when for economy's sake the coal is got by blasting, there is great risk of a flame being lighted which may communicate with other places or set fire to the coal. Presence of mind—a virtue often wanting—may in the outset extinguish a flash of this kind, which if not instantly combated may soon become very serious. A fire produced in this manner, or by the spontaneous combustion which arises in the small coal of certain seams, in a short time produces such a smoke and "stythe" that it can only be approached on the windward side, and frequently makes it needful to retire to some distance and bar off or isolate the district. In such cases dam-doors, the frames of which have been prepared beforehand at suitable spots in the main drifts, may perform excellent service. Perhaps these are nowhere seen to greater advantage or more practically useful than in the great under-sea collieries of Whitehaven, where the Earl of Lonsdale has judiciously had the lintels, &c., of dam-doors prepared in the stone drifts between faulted districts of coal.*

In the last chapter we have treated of the methods of ventilation in practice where due attention is paid to that vital subject; but we have here two questions to answer, viz., why is it, that with so many examples of what can be well done, a large part of our collieries should be in a condition far from satisfactory? and how does it come to pass that every now and then a hecatomb of victims has been sacrificed in a pit supposed to be a model of efficiency? To these we may reply: 1st, that thoughtlessness and opposition to discipline among the men, and ignorance of principles and of good practice, with parsimoniousness, among the masters and managers, are far too common; and 2ndly, that the sources of accident are so numerous, and often so obscure, that no amount of precaution can be expected to obtain perfect security. Though neither men nor owners are open to the sweeping charges of recklessness often brought against them, we must expect, as long as we find so commonly among the pits' company careless, unsteady, or over-daring rule-breakers, and collieries managed by a shopkeeper or joiner, or half-educated young "gentleman," a nephew of the owner, that accidents will occur, which would be certainly preventible under better auspices.

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* In August, 1864, I had the opportunity of seeing how promptly efficient dams were thus put in to isolate the workings of the new, or Forster's district, where the gas had fired in the dip drifts.

My own experience on this latter head, obtained from close inquiry for the Government into the causes of several heavy explosions, before the system of inspection was commenced, and from frequent visits to collieries in most of our districts, is strongly confirmed by the often-repeated statements of the inspectors, that a great amount of good would be effected by local schools having a technical aim. And yet, strange to say, although it is a subject involving the health and life of 400,000 persons directly employed in our coal mines, no approach has been made, except at Bristol, Wigan, and an abortive attempt at Glasgow, to supply that kind of knowledge on mechanics, the nature of gases, &c., which is so desirable for the overmen and their deputies.*

In what concerns the ventilation, a dangerous state of the mine may arise as follows:—

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* The new educational course opened at Newcastle in 1871, and more recently at Leeds, is at last a good step in this direction. The requirement under the Act of 1872 of certificates is working a great change.

1. Absence or deficiency of ventilating power in the shafts.

2. Injudicious plan of workings, or inattention to doors, stoppings, size of air-courses, &c., whereby an abundant current at the shafts is lost before it gets to the faces of work.

3. The insecure position of goafs, or wastes, or even small lodgments for gas, with reference to the air-currents which have to travel past men who are using open lights.

4. The absence of sufficient bratticing in the bords or drift ends.

5. Dependence on too many doors.

6. The occurrence of falls in the air-ways or working drifts. Presence of much fine coal-dust.

7. The interruption of the ventilating current, by repairs in the shaft, by drawing water, or by the furnace or wind-machine going wrong.

8. A sudden change of weather, especially a turn of wind to the south-west, with lower barometer and higher temperature.

9. The emission of gas by blowers, or by bursting in from roof or floor, in such quantity as to overpower the ventilation.

In this latter case the use of safety-lamps can alone give security, and since their introduction brings into play a new set of conditions, it is imperatively needful to draw up special rules regarding them, and in the interest of the owners and the bulk of the men to visit severely all the infringements of regulations which close surveillance can detect.

We cannot do better, in order to show what are the requirements in connection with the use of safety lamps, than quote the Special Rules as laid down for the extensive colliery of Seaton Delaval, under the able management of Mr. T. E. Forster.

1. In every part of the said colliery, where the pillar working or broken is in operation, stations will be fixed upon by the viewer, where each workman's safety lamp will be examined and securely locked.

From those stations no workman is to take a safety lamp for use in the pillar working or broken, without its having been examined and securely locked by the overman, inspector, or deputy.

The overman and inspector to have full power to direct the workmen how to use their safety lamps during the time of working; and it is particularly enjoined that every workman strictly attend to such directions. No lamp to be used on which there is not a tin shield. None but the overman, or similar officer in authority, to be allowed to carry a lamp key.

2. Should any accident happen to a lamp whilst in use, by which the oil is spilt upon the gauze, or it be in any other way rendered unsafe, the light to be immediately extinguished by drawing the wick down within the tube with the pricker; such lamp to be directly taken out to the station where the lamps are examined, and not to be again used until after having been properly examined by the overman, or other responsible person, on the in-bye side of which station towards the broken workings, no candles are to be taken.

3. Should any workman using a safety lamp detect, by the usual indications, the appearance or presence of fire-damp, he is first to pull down the wick with the pricker, as before-mentioned, and then to retreat to the lamp station and give information of the same to the nearest responsible person, it being strictly forbidden for any workman to continue to work in a place where such indications have been observed by him; and should the flame continue in the interior of the lamp after the wick has been drawn down, the lamp then to be cautiously removed, and no attempt whatever to extinguish the flame by any other means to be adopted by the workman.

4. Every hewer, putter, or other person, to whom a safety lamp is intrusted, is hereby strictly prohibited from interfering in any way whatever with the lamp, beyond the necessary trimming of the wick with the pricker. The lamp in no case to be hung upon the row of props next the goaf or old work, and not to be nearer the swing of the gear, on any occasion, than two feet.

5. Should any hewer, putter, or any other person whatever, in charge of a safety lamp, in any case lose his light, he is to take it himself to the station where the lamps are examined, to be relighted,

examined, and locked by the overman, or some other responsible person, before being again used.

6. It is expressly directed that any person witnessing any improper treatment of the safety lamps by any one, shall give immediate information to the overman in charge of the pit, so that a recurrence of such conduct may be prevented by the offending party being brought to justice.

7. Any person found smoking tobacco in any part of the said colliery where the safety lamp is used, or with a tobacco pipe found in his possession, will be liable to be taken before a magistrate. No matches, under any pretence whatever, to be taken down the pit.

8. No putter, pony-driver, helper-up, or other person, is, under any pretext, to carry a lamp during his work, except in special cases, where the parties have leave to do so from the viewer. Lamps will be hung along the going-roads, to afford sufficient light for the performance of the work.

9. Every person using a safety lamp to receive the bottom part of the same himself from the hands of the lamp keeper then in the pit. The gauze to be taken home at the end of each shift, by the person using it, for the purpose of having it properly cleaned before being again used.

10. Any person acting contrary to the above instructions will be liable to be taken before a magistrate, in order that the lives of the workmen employed therein may be duly protected. And any person informing against any offending party or parties will, in every case, be handsomely rewarded. No riding on loaded cages except under special arrangement. Signals, see Act of Parliament.

11. The hewer that keeps his safety lamp in the best order for a quarter of a year, will be entitled to a premium of *5s.*; and for the second best 2*s.* 6*d.* The putter to be entitled to 2*s.* 6*d.* for the same length of time.

It is a moot point whether the men should take home the lamp gauzes to clean, or whether it should be done for them by the colliery. But we cannot fail to reprobate the neglectful plan pursued in some mines of throwing upon the colliers the burden of purchasing their lamps, and thus exposing them to the temptation of buying cheap and unsafe gauze. Nor can one think without ire of the dirty, oily state of the battered Davy that one has seen in some of the colliery offices of central districts, kept for a safeguard (?) in case of fire-damp being feared as an occasional visitor.

3. *Accidents in Shafts.*—The breakage of the rope or chain takes place rarely from bad quality, more often from too long wear and tear of the material. Sometimes a want of proper horns or arms to the drum, or a settlement of the ground at the shaft top, may throw the rope on to the axle, and thus sever it. Any inequality in the surface of the rope-roll which makes the rope lap irregularly, and thus communicates a heavy jerk to the weight in the shaft, is dangerous, especially with wire rope. So also is the adherence to small-size drum and pulleys. Many lives, again, are lost under the old system of raising the men in skips or boxes hanging free, particularly if they be suspended by two chains only. The introduction of cages and guides in the northern districts has greatly lessened the liability to this class of accident. Against the falling of stone, bricks, &c., from the sides, a good walling and occasionally overhauling and clearing from rubbish, with a bonnet or cover over the cage, are efficient protections. The numerous deaths from falling into the shaft, either from surface or from mouthings opening into upper seams, may be in great measure prevented by the use of light railed doors or wickets which guard the orifice until the cage comes up and lifts them out of the way for the time only during which access is needed. Overwinding, one of the most frightful of accidents, where the cage with its human freight is carried up violently against the pulleys overhead, is to be avoided by the employment of only the most trustworthy engine drivers, the use of the steam-brake, a sufficient height of pulley-frame, and

perhaps in some cases the use of the safety apparatus referred to above in Chapter XIV.

The carefully prepared statistics of H.M. Inspectors of Coal Mines group the accidents under different heads, and among other valuable results show that the casualties in shafts have in the last thirty years been greatly reduced. Whilst in the years 1851 to 1855 one death per annum occurred by shaft accident out of 1,000 persons, the ratio has of late years, and by a steady process of improvement, been reduced to one death out of 3,300 persons employed. Greater caution has come to be exercised by all parties, superior tackling is used, and close attention is given to its examination; but, as a rule, the ingenious contrivances for arresting the cage when the rope breaks, have not met with extended favour. The comparatively very small number of accidents from "over winding" redounds to the credit of the engine-men of the country and the condition of their appliances; but some recent cases accompanied by a sad loss of life, have drawn more attention to the subject of special contrivances for arresting the load when it is raised too high.

Detaching links or hooks were proposed thirty years ago, but in some, at least, of the forms suggested were positive sources of danger. Of late a number of others have come to the fore, and what with popular pressure, and the suggestions of Government officials, are being adopted in great numbers. Whether this is altogether a wholesome way of advancing, and whether the introduction into the winding gear of any piece of complication is not a new source of danger, are questions upon which opinions will differ. Most of these disengaging or safety links and hooks are patented, and run a close race of rivalry. Some few have been offered freely as a boon to the mining world. Mr. Aytoun, W.S., of Edinburgh, in 1860, proposed a hook formed of three parallel plates of steel, the central one of which, standing out in its normal position beyond the side pieces, should, on over winding, be drawn through a narrow ring, and thus cause the central plate to push the shackle by which the load is suspended off its usual seat, so that it falls through a vertical slot, and disconnects the cage from the rope. Mr. J. Bryham, of the Rosebridge Colliery, nearly about the same time introduced the hook, on a similar principle, which is shown in Fig. 49 under three aspects. Here *a a* are two parallel plates of wrought-iron, with vertical slot *b*; *d* is the central plate, *f* a brass pin, which keeps it in a projecting position till the pin is sheared by *d* coming in contact with the iron plate *g*, when the shackle will be pushed from its bearing to the slot *b*.

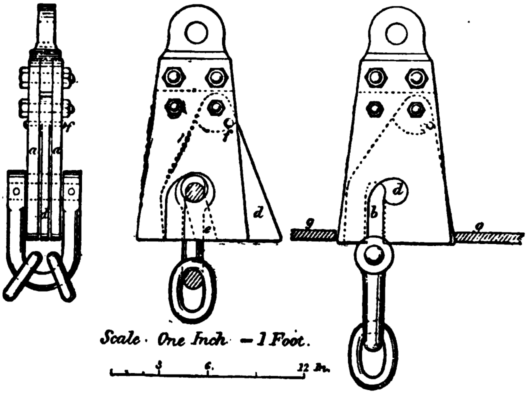

Fig. 49.

The cage is then arrested by strong cams or catches attached to the pit-head framework.

King's, Ormerod's, Walker's, and Ramsay and

Fisher's hooks involve the additional feature of throwing out clutches when over winding, which suspend the cage to the framing. They are all fairly before the public, abundantly advertised; and it may be hoped that the selection of the best of them may aid in the good work already done by the rooting out of the neglect and slovenliness which were once too common.

4. *Holing into Old Works.*—A great risk is incurred in approaching old abandoned workings, sometimes from their containing fire-damp or carbonic acid, but more commonly from their having reservoirs of water ready to escape under great pressure, and certain, if incautiously tapped, to occasion a disastrous inundation. The danger is often sadly magnified from the lamentable and unbusiness-like absence of proper plans of the old works. It is recognised on all hands that the only prudent method of advancing under such circumstances is with bore-holes in front and flank, kept five or six yards ahead of the working, and with tapered wooden plugs ready to drive in as soon as water is tapped. The subject of the registration of mine plans has often been mooted, and by some of the highest authorities, as essential for the preservation of life and property; but under the wretched notion of letting things alone, this humane precaution was not till 1872 adopted as a public measure. If such plans, drawn to the true meridian, instead of the ever-varying magnetic line, were deposited in some accessible office, many a valuable life would be saved.

5. *Miscellaneous Accidents.*—The liability of men and boys to be crushed and run over by trams and underground trains, and especially on inclines, must be met by strict discipline, and by providing separate travelling roads, refuge places, and sufficient signals. Many

accidents occur from people passing across the bottom of the drawing shaft, which are simply avoided by having a suitable passage at the side, and insisting on its being used. As to the casualties which occur from blasting, they ought to be entirely eliminated from the list: the firing of a shot in the coal, apart from the presence of fire-damp, entails no risk on careful men; and in sharp stone liable to strike fire, the use of bronze-headed tamping-bars and the safety-fuze should be generally adopted. The deaths caused by carbonic acid and after-damp are too often due to the want of thought or the ignorance of the sufferers themselves, and not unfrequently to the generous daring with which they have rushed forward to succour others. A better knowledge of the properties of the gases, greater caution in entering unfrequented places, and improved ventilation must be looked to for the reduction of this class of perils.

It may excite surprise that men should be found willing to confront so many dangers, coupled with hard work in cheerless gloom. But familiarity with subterraneous works shows a different side to the picture, and, although plenty of bad cases might be cited, the larger, well-managed collieries offer, as the life-statistics prove, by no means unhealthy working places. The gaseous enemies which invade them are invisible, and are therefore even too readily forgotten; and the work, though heavy, is simple, and requires very little expenditure of thought. Moreover, the wages are, in spite of strikes and associations, as a rule, very good, nay, in some cases exceedingly high, if men only choose to work, and have acquired the degree of skill which we find, even in coal-cutting, will greatly distinguish certain hewers above others. Our Cornish miners, fagged by climbing, and by high temperature, contending with rocks of excessive hardness, and, after all, earning rarely more than £3 10*s.* or £3 15*s.* per month, offer a strange contrast to colliers of the North, who can commonly make their 6*s.* per day, and have often houses free of rent, and coals, and schooling for their children at a nominal charge; and to the Welsh colliers, who in a good stall of the rich Aberdare coal will get their 8*s.*, or even 10*s.*, a day.*

Truly, as contrasted with other men, the colliers in well-conducted pits have not so much to grumble over as they are made by their interested friends to believe; nor do the methods so popular among them of strikes and combinations, and proposals for interfering with the management, appear suited to gain them enduring safety and comfort. In and about the pits, especially, it is plain that the spirit of insubordination, and opposition to the masters and their rules, are inconsistent with the well-being of either party. And a ship in a storm, with all the sailors commanding, would not be in a more dangerous plight than a fiery colliery with its discipline sapped, and no one in full authority.

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* To quote a special instance, the highest wage made in March, 1866, at the Navigation Colliery, Mountain Ash, was no less than 12*s.* 8*d.* per day for twenty-three days. It must be noted that the figures above given belong to a prosperous period, and that in the depression of trade between 1874 and the end of 1879, wages have also fallen.

CHAPTER XIX.

DURATION OF THE BRITISH COALFIELDS.

THE astonishing increase in the consumption of coal within the last half century has kept pace with the advancement of various arts and sciences, and has necessitated a constant improvement in the methods and appliances used in its extraction. Our knowledge of the mineral resources of this and other countries has during the same time been placed on a footing so much more definite than formerly, as to excite in the reflecting mind, conversant with the heavy drain now making on our coalfields, a reasonably-founded anxiety as to their duration.

Contented security may in its ignorance of the facts assume, and persons interested in maintaining their own special trade, may represent that the coal-seams are "practically inexhaustible," and may stigmatise as "alarmists" those who would invite attention to the bearings of a question so vital to our immediate posterity; but a fair examination of the statistics above set forth, and of the local conditions of our coal-bearing districts, will show that at least the time for prudent forethought has arrived.

In the last few years, accurate surveys have shown the certain boundaries of most of our coalfields, formed by the actual rise to the surface of the ground of the foundation rocks, in and under which no coal at all is contained. In some other instances they exhibit a surface boundary, beyond which much may be hoped for, but where in many cases the uncertainty and expense will greatly reduce the value of the extended territory, or, in other words, increase the average charge at which the coals will be raised.

Knowing, therefore, most of the edges, and pretty nearly the depth of all our recognised stores of coal, let us remember at what rate we are now digging them out. The amount of coal raised in this country in 1864 shows that, supposing 1,300 tons be obtained per foot thick per acre, out of 1,600 which it actually contains, there are now clearing out in every hour, day and night, for every day in the year, 4 acres of coal of 2 feet thick—1 acre every quarter of an hour! There can here be no reproduction, nothing to grow again; "we are drawing," as an able writer* has well put it, "more and more upon a capital which yields no annual interest, but once turned to light, and heat, and force, is gone for ever into space." How fares it with some of our best-known districts?—do they, or do they not, show symptoms of a change? In Shropshire the workings have passed away from the exhausted western side of the field to group themselves along the eastern: in Staffordshire, the famous Dudley seam will in a few years be as a tale that is told: in the great northern coalfield almost every available "royalty" is taken up, large tracts have been cleared out, and already progress is made in leaving *terra firma* and working out under the North Sea.

It must, then, be understood that the rapid exhaustion of certain districts, and the calculation of what coal remains, are not the speculations of theorists, but the fair deductions from weights and measures, ascertained with a great amount of practical care and discrimination.

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* Mr. Jevons, "On the Coal Question."

I need not refer to the older estimates of the duration of our coalfields, for neither had the earlier writers any idea of the enormous future increase of demand, nor were they provided with the requisite data for reasonable approximations. It was only in the classical coalfield of Durham and Northumberland that the position and character of the seams were so well known to the viewers as to admit, many years ago, of approach to accuracy.

Mr. Greenwell, a colliery viewer thoroughly acquainted with the district, taking the quantity producible from each several seam, including what lies below the magnesian limestone, as well as *a width of two miles under the sea*, calculated in 1846 that 331 years would, at the then existing rate, exhaust the whole area. At that time only 10,000,000 of tons per annum of round coal were raised. In 1854, when the amount had reached 14,000,000, and a larger proportion of small coal came to be available, Mr. T. Y. Hall, also a member of the Northern Institute of Mining Engineers, estimated the duration at 365 years, but stated that it would be reduced to 256 years if the demand were to increase to 20,000,000. And now, since the output in 1878 reached upwards of 29,000,000 of tons, and there is every reason to expect a constant increase of production, it is obvious that the time thus estimated must be greatly abbreviated, and that Sir William Armstrong, in calling attention to the rapid exhaustion of coal, in his address at Newcastle in 1863, based his argument on no unsound foundation.

In 1859, Mr. Edward Hull attempted the more ambitious task of making a similar calculation for the whole of the British coalfields. As a laborious geologist on the Government survey, Mr. Hull had enjoyed excellent opportunities of learning the structure of several of the coal districts, but with respect to others had to rely on *data* of various authority. In each case he has measured the available area, has adopted from the sections an average thickness of workable coal, and deducted from the total quantity thus obtained an allowance (no doubt difficult to agree upon) for the denudation of the upper seams. A large fraction is then allowed for quantity worked out, and loss in future workings, leaving us a total amount in stock of about 80,000,000,000 tons for the entire kingdom. All the coal lying at a greater depth than 4,000 feet is excluded from this estimate as being beyond reach, but a very large area, amounting to an increase of one-third, is added to the coalfields, for extension beneath newer formations.

We may cavil at some of Mr. Hull's numbers, and disagree with his notions about the limit of depth, but his little book is a creditable summary of the chief features of our coal resources, and his approximate general estimate the only one which is so founded on facts as to deserve attention; whilst especially on the subject of reaching coal beneath the Permian and Trias formations, no previous author has approached it with the same amount of practical knowledge. When we pass from the descriptive part to the reasoning on the coal supply, we find arguments of a more questionable character, some of which have since been combated by Mr. Jevons in his clear and forcible work, "On the Coal Question," whilst others appear to have led to false conclusions as to the rate of progression of the consumption.

It seems that in twenty years, ending 1860, the quantity of coal raised in Great Britain was more than doubled; but are we thence justified in believing that in the next following twenty years it will be again doubled, and so on in geometrical progression? On this view of the subject, little more than a century would see this country utterly deprived of the mainspring of its mercantile greatness. Manufactories without their motive power, iron-furnaces blown out, railway trains brought to a standstill, steamers replaced by sailing ships, our streets left to the gloom of oil lamps, and our firegrates empty,—such would be the dismal prospect of a nearly approaching time, could we give credit to such an inference!

I think, however, that the assumption is based on a fallacy, and that although the numbers for certain years appeared to fit such a conclusion, the increase to our production of from 2,000,000 to 3,000,000 of tons annually, serious as it undoubtedly is, will keep us within comparatively moderate figures for a long time to come, and at all events defer, as regards the country at large, the evil day for two or three centuries.* But

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* In France the production of coal has similarly been doubled after every period of twelve to fourteen years, thus:—

Year.	Tons.
1789	250,000
1815	950,000
1830	1,800,000
1843	3,700,000
1857	7,900,000
1872	15,800,000

but the Comité des Houillères Françaises think that the same rate of crease cannot possibly be kept up.

beyond this, it is a question whether even the present rate of increase of production can long be continued, and whether there are not causes at work which will tend to raise the price and limit the consumption. Our special position as the first manufacturing people depends in great part upon the cheapness of our fuel, and any considerable increase in price, as compared with that of other countries, would soon be deeply felt.* At present Belgium, France, and Westphalia are unable fully to compete with us; and English coal takes possession of the seaboard of the Continent, and in numerous cases ascends the rivers for long distances towards the centres of coal production of those countries. And sundry reasons may account for the fact. Nature has been bountiful to England not only in the quantity, but in the comparative regularity of the coal seams. In the best pits in France and Belgium the large, or *round*, coal is seldom more than 45 per cent. of the whole, and the general average is far less. The disturbed position of the beds also renders them more difficult to work, and involves an expense in the mere item of prop-wood alone of 9*d.* to 1*s.* per ton, whilst in many of our districts 2*d.*, in others 3*d.*, on the ton may be the average.

But if we are to be checked in the race, the mischief is likely to proceed in great part from an internal canker, from the irregularity and combativeness of the men. What with the peculiar socialistic views so common among them, and the facility with which their organisation, under skilful delegates, enables them to threaten their masters, the interferences, stoppages, and interruptions to the working of collieries are becoming an evil of such weight as to constitute an additional charge on the ton of coal. It would be quite out of place here to discuss the subject at any length; but it must obviously be taken into account in forming an estimate of our power of production. It might be supposed from the frequent recurrence of strikes, that the colliers, as a class, are ill-paid; but when we find wages of from 5*s.* to 12*s.* a day—the rate for good hewers from Newcastle down to South Wales, we cannot but see that there are other large classes of working men in the kingdom, bringing equal skill and labour to bear upon their task, with a much less satisfactory result. The rate of payment is fairly brought to the test of experiment, being in most districts so much per tub or cart of known capacity; in the north, so much per score or per ton, and each pit having there a weighing machine, at which a man is commonly stationed to watch the weighing on behalf of the colliers.

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* For a masterly treatment of this important argument see Jevons's "Coal Question."

If, therefore, with these inducements to steadiness of work, a skilful collier nevertheless joins in the strikes and agitation for short hours, weekly pays, with all the concomitant idleness, limitation of quantity to be got, exclusion from the pits of boys under a certain age, and various other interferences which may be more or less objectionable in different districts—that man is adding a weight against his own nation in the balance between ourselves and the foreign coal producer.

In a discussion on the duration of coal, we should bear in mind that it is one thing to obtain a certain amount of fossil fuel tolerable in quality, but dear from being wrought under difficulties, and another thing to occupy our present position of raising the best qualities at the lowest prices. Most of our best districts are being stripped at a fearful rate:* the purest household coal of the north, the "Wallsend" of the London trade, the Dudley thick coal, the Wigan cannel, the Aberdare steam-coal—where will they be fifty years hence? And yet there is no help for this; and all we have to see to is that they are made away with to the best advantage. But the question follows: when the cream of our coalfields has thus been enjoyed, what have we to fall back upon to maintain, at least, our large production, even if we are unable to keep up a marked lead? There will be the seams that are coarser in quality, that are thinner or deeper, and those about which there may be much uncertainty, as, for example, where it may be required to sink through overlying formations. A cloud of difficulties arises; but there are rays of light around it: "dirty" coals will be more commonly treated by washing processes—thin seams now neglected will turn out useful; for if we can already work 12 and 14-inch coals in Somersetshire, why should 2 feet be elsewhere called unworkable? And then as to depth, the improvement of both pumping and winding engines is rendering that element of difficulty—within moderate limits—a matter of no very great import.

Here, however, we arrive at a topic fraught with much interest. In South Wales and Lancashire, in the coal measures, and in certain districts where the surface is occupied by the red sandstones of the Trias, we may have coal seams below us at 5,000, 8,000, or 10,000 feet deep. Some of the authors above quoted think that the limit of accessible depth is 4,000 feet, beyond which the increase of temperature would prevent the possibility of working; but a considerable experience of deep mines induces me to believe that the difficulty of temperature may, by due appliances, be overcome to a much greater depth.

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* In order rightly to appreciate the rate of exhaustion of the coal, we must add to the 130 millions of tons returned as raised, a further amount for wasted slack, barriers, faulty coal, &c., of probably not less than 30 millions of tons.

It is sufficiently well known that experiments made in the mines of various countries show that below a certain point of invariable temperature generally reached at 10 to 20 yards, the temperature of the rock and of water contained in it increases at the rate of 1° Fahr. for every 60 or 70 feet of descent.* The air which travels down into the workings is soon heated; but passing off, and thus cooling the walls of the excavations, and constantly replaced by fresh air from above, it enables work to be done with comfort in our deepest present mines. It must be admitted that the first opening of the levels or drifts at a depth of 1,500 to 2,000 feet deep is a hot task; but after finding the thermometer in such cases at from 75° to 88° in a close end, I have observed that when the air has once circulated beyond such points for a period of a few weeks or months, the temperature has sunk by so many degrees as to admit of further working with facility. The most remarkable case of this rapid cooling, with which I am acquainted, is at the Clifford Amalgamated Mines in Cornwall, where, in the 230-fathom level (1,650 feet from surface) the air (July, 1864) was 104 Fahr., and close to the issue of a hot spring of 122°, even higher; but where, in the 220-fathom level (1,590 feet deep), it was only 83°, although when first opening, a year or two before, it had been at 100°.

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* The extreme variations of increment, except where thermal springs are present, are 58 feet to 88 feet for one degree Fahr.

The late Mr. Rogers, at Abercarn colliery, in sinking a shaft in 1851, supplied compressed air to within a few feet of the men at work, which—as I tested at the time—in its escape from the pipe, cooled the pit bottom several degrees. No doubt, therefore, that what with a good ventilating power, and occasionally, it may be, by the aid of compressed air, the first winning works may be quickly reduced below the normal temperature due to the depth, and the subsequent workings be rendered comparatively cool.

It is not commonly known that in the province of Hainault, in Belgium, coal is working at the depth of 2,820 feet (860 mètres), at the colliery *des Viviers*, at Gilly, near Charleroy, and that one pit at the same place has been sunk to the serious depth of 3,411 feet (1,040 mètres).*

With regard to other difficulties offered by great depths, our present best methods of raising the water and coal are, no doubt, capable of dealing with a considerably greater depth than has yet been attained. For still deeper pits it may be suggested either that a plant of engines be established half way down, and the work thus effected by two lifts, or that reciprocating rods as in the *Fahrkunst* or Cornish man-engine may be fitted, as proposed by Méhu, and by Guibal, to bring up a constant succession of coal-tubs; and although such modes have not as yet been made practically economical, we may rest assured that the same art of mining, to which the public is mainly indebted for the improvement of the steam-engine and for the railway, will not rest without further development of its appliances.*

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* Visiting this pit in 1871, the author found the depth to the bottom of a trial staple was 1,064 metres, or 3,489 feet.

If then, as we have reason to assert, our better and more accessible coals are being so fast wrought out as to threaten an early change of conditions, what, it may be asked, can be done to prevent their exhaustion? Our home consumption *must* increase, if we are as a nation to advance in prosperity, and its only check will be from an increase of the price at which it can be delivered to the consumer. This, however, as compared with the cost of production abroad, will be the turning point in our progress. As regards our exports, which have risen since 1841 from 1½ to near 16 millions of tons, constituting above a tenth of our production, it has often been suggested, and by grave authorities, that a tax should act as a check; but such an impost would undoubtedly be open to serious objections. It has been held by certain writers that the exports are sure to diminish because other nations are developing their own coalfields; but a little attention to the statistics given above will show that during the very period of the multiplication, tenfold, of our exports, France, Belgium, and Germany have been increasing their output no less remarkably than ourselves. The fact is, that all the active nations of the world are every year requiring more coal than before, and a fair inference is that what goes abroad as well as what is consumed at home will be an increasing quantity, until a higher price per ton operates as a check.

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* An interesting inquiry into this subject, with suggestions for new apparatus, will be found in Devillez, "*De l'Exploitation de la Houille à la profondeur d'au moins mille métres.*" Liége, 1859.

But although we are thus carried away by the stream, it behoves us to take every precaution to navigate our craft in the best manner. There are many things in our individual and collective mode of treating coal mines which should be better looked to in the interest of those who follow us. We must admit that amid the pressure of competition, it is hardly possible to do otherwise than take out in the cheapest way whatever pays best; whence the strictures sometimes passed upon our wasteful procedures are, however true as regards the nation at large, scarcely just to individual workers.*

The great waste of small coal, although of late years less flagitious than formerly, is still a lamentable extravagance; for it is not too much to say that millions of tons of it are buried up annually, in gobs, stowage, crushed pillars, &c. The remedies which we may hope to see gradually applied, are as follows:—

1. The best selected mode of laying out collieries, both as regards freedom from crush and creep, avoidance of an excess of narrow or *strait* openings, and judicious direction of the bords or working faces.
2. The more general washing of smalls.
3. The extended use, partly by means of new forms of furnace, of slack and the smaller varieties of screened coal (*pease* and *duff*) for manufacturing purposes.
4. Employment of the best methods of coking.

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* "Il est impossible en voyant cela, de ne pas pressentir qu'on va trouver à chaque pas les Anglais abusant des avantages naturels qu'ils rencontrent dans les gîtes houillers de leur pays."—Extract from a report. Burat, "*Matériel des Houillères.*" 1865. It is satisfactory to be able to inform our French critic that, at the colliery which suggested his remark, the state of things is already improved, simply in consequence of the increasing demand for slack for manufactories.

5. Improvement in the making of coal-bricks or "patent fuel,"* and

6. Last, but not least, the application of coal-cutting machines, some of which appear to be verging close on practical utility, will be the advent of a saving that may give us years of prosperity.

A miserable sight it is too, to see a part of a seam, the "roofs" or "benches," as the case may be, when a parting becomes so thick, as to prevent the whole group of beds from being conveniently worked together, abandoned and left uncared for, with the probability that when the present generation has died out, there will be no sign to show that there is still lying there, neglected, a tract of what at some future day might offer a profitable working. And intolerable, again, it is to observe corners and plots of ground sacrificed on account of the inconvenient division of properties on the surface; when often the avarice or ineptness of some holder of surface fields operates as a bar to the regular working of colliery proprietors, and of course as an obstacle to the development of the national store.

It appears hardly credible, when we consider how easily these sources of sheer waste might be indicated in the maps, and when we remember the uncertainty and the danger to human life of approaching old workings, that no arrangement was, till 1872, made for the registry and preservation of proper mining plans.

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* The large proportion of *small* in the Belgian and French coal has led the continental colliery proprietors and machinists to devote much attention to the manufacture of *briquettes* or *agglomérés*, which, when well made, meet with a large sale. Opinions at present vary as to the best method of cementing the coal fragments, and much stress is laid on the substitution, for pitch or tar, of farinaceous matter, as first, I believe, practised at Fünfkirchen in Hungary.

In no other country in Europe was there such a laxity in a matter of vital importance to our successors. Under the first Inspection Act every colliery was bound to keep up plans on a certain scale; but how partial was the advantage, when at the end of a lease the documents were subject to be lost or destroyed! Under the new Act the Government, when a mine is abandoned, insists on the deposition of "accurate plans," to be preserved under the care of the Secretary of State. And if lessors and lessees, alive to the national importance of these documents, co-operate in rendering available at a future day those tracts which it may be difficult to turn to present account, we shall no longer remain open to the charge of an unworthy stewardship of the riches which a bountiful Nature has committed to our care.

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